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Coil-EEFL Tube as Supreme Incandescent Light Source with Zero Electric Power Consumption, Astronomical Quantum Efficiency, and Long Life

By Lyuji Ozawa

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COILEEFLTUBEASSUPREMEINCANDESCENTLIGHTSOURCEWITHZEROELECTRICPOWERCONSUMPTIONASTRONOMICALQUANTUMEFFICIENCYANDLONGLIFE

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Introduction

Human have daytime activity for more than 5 million yeas under slightly overcastting sky. The naked eyes of the human activity adjust to daytime sceneries that give 10^{25} visible photons (m^2, s)$^{-1}$; corresponding to luminance (330 cd, m^{-2}) or illuminance (330 lm, m^{-2}). The human activities extended to nighttime with the illumination of the dark. First illumination source was made by the fire flame that was made by the chemical reaction with oxygen in air, which the heat temperature of the flame was determined by amount of change in entropy. The illumination by the fire flame has called as candescent lamps. The word of the candescence comes from the ancient Greek that means flame of fire. After finding of invisible electrons, the lighting sources shift to the incandescent lamps that use moving electrons in metals or solids and gases. The initial incandescent lamps use the heated metal filament in vacuum. The next incandescent lamps are the fluorescence lamp (FL) that uses the floating atoms in vacuum and moving electrons in the gas space. The lights originate from the excited Hg atoms that emit the invisible UV lights. The phosphor screen transduces the invisible UV lights to the visible lights. Now, the light emitting diode (LED) lamps are emerging as the new light source.

The lighted incandescent lamps consume electricity that is generated from the electric power generators. According to the recent report of COP 21 (Conference of Particles 21), the consumed electric power by the illumination on the world is around 31 % of the total of the generated electric power on the world. A reduction of the electric power consumptions of the incandescent lamps is an urgent subject for the environmental protection of the Earth. However, we do not know the exact amount of the consumed electricity by the individual incandescent lamps. We must know about the consumption of the electric energy of individuals of the incandescent lamps scientifically. Then, we may select an incandescent lamp that consumes less electric power for the contribution to the green energy project.

I. Brief Summary of Principals of Established Incandescent Lamps

The incandescent lamps use the moving electrons in metal filament, or solids, and gases in vacuum-sealed glass tube. They are figurative materials by the naked eyes. However, the electrons, atoms, and gas are invisible by the naked eyes. The studies on the incandescent lamps step in the invisible electrons and atoms in the materials and in the gases that are the subjects for the scientists. The science reveals the invisible bonding mechanism of the materials. The metals are formed with the bonding electrons in the upper shells (s, or p, d shells) in the metal atoms. The electrons in the metals move on the upper orbital shells of the metal atoms. No vacuum space involves in metal. The pure solids of the semiconductor compounds are formed with the shared electrons of the atoms; i.e. covalent bonds that do not allow the moving electrons. As the solids contain a small amount of the different atoms as the impurities, the impurities give the extra electrons or lack of bonding electrons (holes) in the bonding. Then the extra electrons in the solids move on

Author: Japanese Government licensed Consultant in Science, Litang Lu, Changping Qu, Beijing, China. e-mail: Rotsun4@hotmail.com

in the narrow vacuum space between atoms at lattice sites of the crystallized solids. The atoms in the gas phase float in the vacuum by the Maxwell-Boltzmann distribution. The electrons move on in the vacuum between atoms. We will briefly explain the differences of the moving electrons in the metal-filament, crystallized semiconductors, and the vacuum in the incandescent lamps. The incandescent lamps require the electrode at the both ends of the lighting devices. The individuals of the incandescent lamps have the advantages and limitations as the electric power consumptions and operation life. After the clarification, we may find a candidate of the incandescent lamp that contributes to the green energy project on the world.

a) Metal-filament lamps

The typical incandescent lamps have used the heated thin metal filaments to the temperatures higher than 1000°C by the Joule Heat (= I^2R). The metals are formed with the metallic bound with separated distance at around 10^{-10} m. The moving electrons in the metal filaments unavoidably have the electric resistance R that is caused by the thermal perturbation from the thermally vibrating metal atoms at lattice sites. The illuminance (lm m^{-2}) of the metal-filament lamps changes with the temperatures that are heated by the Joule Heat. The Joule Heat consumes the large amount of the electricity by the I^2R. Figure 1 schematically illustrates the thin W-filament lamp in operation. The demerits of the thin metal-filament lamps are (i) in air, heated metal has chemical reactions with oxygen in air. Consequently, metals change to oxide compounds. (ii) In vacuum, heated metal atoms evaporate to the vacuum. The evaporation of the metal determines the operation life. The metal filament lamps have essentially short operation life, less than 5 x 10^2 hours. The metal-filament lamps do not contribute to the green energy project with the large amount of the Joule Heat and short operation life.

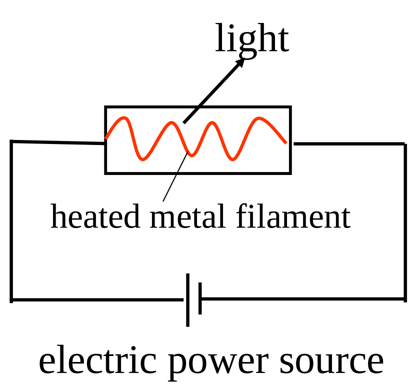


Figure 1 : Schematic explanation of metal filament lamp

b) Solid LED lamps

Recently; the light emitting diode (LED) lamps are emerging as the incandescent lamps. The LED lamps are a kind of semiconductor. Semiconductors are composed with covalent bonds. Covalent bounds do not allow conduction of valence electrons in atoms at lattice sites. They are electric insulators. The wave function of atoms at lattice sites overlaps each other that give the wide energy bands. Pure crystals of semiconductor are essentially electric insulators. As the compound crystals contain the small amount of the impurities, the impurities provide the electrons (n-type) or holes (p-type) in the very narrow vacuum space in the crystals. Then, the semiconductor compounds allow the moving electrons in the narrow vacuum space between atoms at lattice sites. Figure 2 schematically illustrates the narrow vacuum space for the moving electron in the semiconductor.

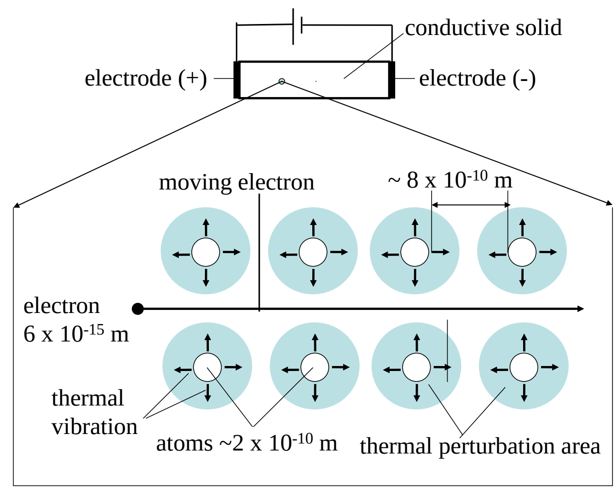


Figure 2 : Schematic illustration of moving electron in narrow vacuum space between atoms at lattice sites in semiconductor crystal

The moving electrons in the semiconductor inevitably receive the thermal perturbation from the thermally vibrating atoms at the lattice sites. The thermal perturbation does not influence to the energy band. The thermal perturbation gives the electric resistance R to the moving electrons. As if the semiconductors have the junction of n- and p-types, the junctions may have the recombination centers for the moving electrons and holes (EHs). The recombinations of the EHs at the recombination centers release the lights. The light emitting diodes (LED) are produced with the junction in the semiconductor crystals. The LED must have the metal electrodes at the both sides for the direct injection of electrons and the collection of the electrons from the LED crystals. Figure 3 illustrates, as an example, the structure of the commercial LED lamp [1].

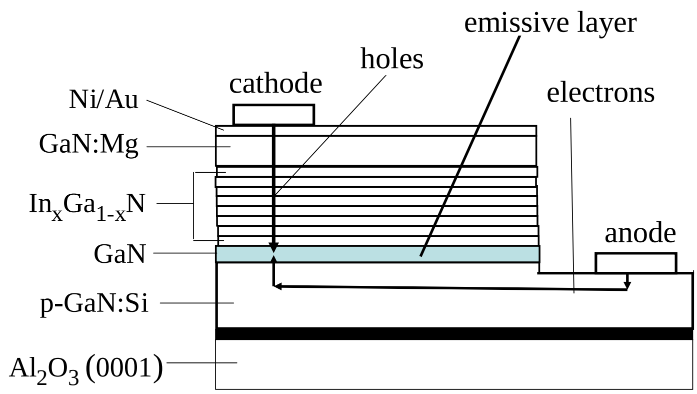


Figure 3 : Structure of LED lamp. Junction generates lights by recombination by EHs

The injected EHs into the LED move on in the narrow vacuum space {$(10^{-9})^3$ m^3} between atoms at the lattice sites in the crystals. Naturally, the electrons have R. If there is no R in the LED that is the superconductive LED, there is no loose of the kinetic energy in the crystal; IR = V = 0. The electrodes of the LED hold with the constant voltage with the change of the injected EHs. All injected pairs of the EHs may recombine at the luminescent centers in the ideal LED or may collect by the electrodes. We assume that the numbers of the emitted visible photons from the ideal LED corresponds to the numbers of the injected pairs of the EHs to the LED lamp. Although it is practically impossible to have the ideal LED lamp with R = 0, we may calculate the numbers of the injected electrons from the anode electrode to the lighted LED lamp. The cathode injects the same numbers of the holes to the LED. The figure of the merit of the incandescent lamp is given by the ratio of the numbers of the emitted photons (lights) by one pair of the injected EH. The ratio is the quantum efficiency η_q. The ideal LED lamp should have $\eta_q = 1.0$ as the maximum. For illumination of a given room in unit size (1 m^2) with 10^{25} visible photons (m^2, s)$^{-1}$ with the daytime scenery, the LED lamp should be operated with the DC electric current I = 1 x 10^6 A (= 10^{25} x 1.6 x 10^{-19} Coulomb per second) that is 10^3 kA.

The LED lamps are not produced by the superconductive solid. The moving electrons in the LED lamp lose some amount of the kinetic energies by the Joule Heat before reaching to the recombination centers. Naturally the η_q of the LED is less than 1.0. The reported η_q is around 0.5. The LED lamp as the illumination source must operate with 2 x 10^6 A (= 2 x 1 x 10^6 A). The LED lamp generate a huge amount of the Joule Heat (= I^2R). If the R = 0.3 Ω per LED lamp on the dais in 1x 10^{-4} m^2 [1], the power consumption W_{LED} (=VI) of the practical LED lamp on the dais (1 x 10^{-4} m^2) is calculated as W_{LED} = 6 x 10^6 watt (= 2.8 V x 2 x 10^6 A) = 6000 kW. The 3000 kW among them consume as the generation energy of the lights and residual 3000 kW consume with the heat generation of the LED lamp. The calculations indicate that the LED lamps are the power hungry illumination source. There is a limitation of the light intensity from the heated LED lamps by the Joule Heat. The luminescence centers (e.g., impurities) in the LED lamps diffuse out from the junction of the LED lamp at the temperatures above 70°C. The LED lamps must operate at the temperatures below 70°C. As described above, the LED incandescent lamps may contribute to a small room of the green energy project.

Followings are not the pure material science. It is the ophthalmology. If your eyes directly observe the lighted LED spots on 1 x 10^{-6} m^2 dais, your eyes may detect the bright light spots, like as the stars in the dark night. The LED lamps may supply the good decoration light sources in the night that directly observe by the naked eyes. For the illumination purpose, you should consider the total numbers of the photons on the unit surface area (m^2) in the illuminated room, that gives the 10^{25} photons (m^2, s)$^{-1}$, corresponding to the luminance (330 cd, m^{-2}) or illuminance (330 lm, m^{-2}). However, we may find neither luminance nor illuminance of the LED lamps. The LED lamps are actually evaluated with the erroneous luminous efficiency (lm, W^{-1}) that is used in the study on the colorimetry, not the lighting source. In addition, the W in the luminous efficiency is the energy of the visible lights that are measured by the bolometer. However, the reported W is not the energy of the lights. They take the consumed electric energy (watt) of the LED lamps. They do not know how evaluate the performance of the LED lamps.

From the quantitative calculations by the commercial LED lamps, one may reach a conclusion that the LED lamps may have a small room to the contribution of the green energy project; except for the export business of the most advanced semiconductors facilities for the production of the LED lamps in other countries.

c) Fluorescent lamps

Another commercial incandescent lamp is the fluorescence lamp (FL). The studies on the FL tubes have the long history more than 80 years since the invention [2]. The FL tube is composed with very simple structure as shown in Figure 4. The vacuum-sealed FL tube has the metal electrodes with the Ar gas pressure at around 931 Pa (= 7 Torr), and the small amount of the Hg droplets on the phosphor screen. After the invention, there were many reports for the optimization of the FL tubes. The systematic studies of the FL tubes in USA had terminated on early1970s. The published reports are summarized in the Handbooks before 1970 [3 to 7]. If you learn the properties of the FL tube from the Handbooks, you may surely reach a conclusion that the present FL tubes in the simple structure are produced with the mature technologies. The typical commercial FL tubes on the market are expressed as the 40W-HCFL tube. The 40W means the electric power consumption of the FL tube for the generation of the lights.

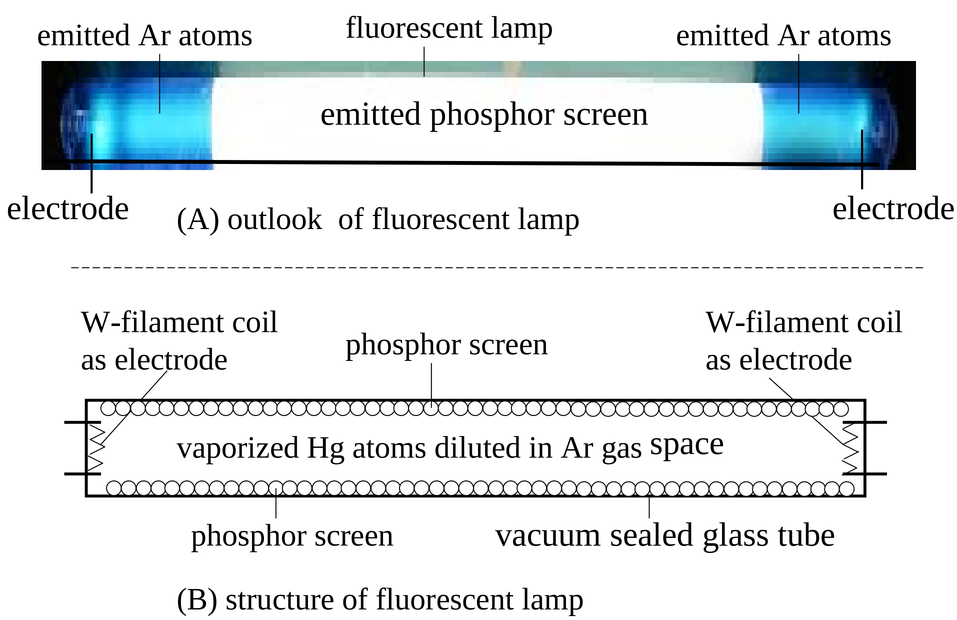


Figure 4 : Schematic explanation of FL tube. (A) is outlook of lighted FL tube and (B) illustrates structure and components of FL tube

We have carefully studied the FL tube from the fundamentals; we have found the premature technologies of the currently produced and evaluated FL tubes. The present FL tubes are produced with (i) many hypotheses without the scientific proof, (ii) misinterpretations of the observed results, and (iii) especially the invalid evaluations of the performance of FL tubes. Those conceal the latent superiority of the FL tubes as the incandescent lamp.

The study on the high quality of the FL tube involves in the most advanced material science, surface physics of the materials, and advanced gas physics. From the view points by the advanced science research, the FL tubes hold the advanced features. The advanced features of FL tubes as the incandescent lamp are concealed by the evaluations of the established premature technologies. By the removal of the invalid technologies described in the established Handbooks, we may reveal the superiority of the FL tubes over other incandescent lighting sources. We have found the coil-external electrodes FL tube, coil-EEFL tube, that have (i) the electric power consumption of the external driving circuit will be nearly zero, (ii) the superconductive vacuum between Ar atoms (R = 0), (iii) astronomical high quantum efficiency $\eta_q = 10^{13}$ photons $(m^3, s)^{-1}$, and (iv) prolonged operation life longer than 10^6 hours. The developed coil-EEFL tubes have the supreme quality as the incandescent lamp. The developed coil-EEFL tubes may significantly contribute to the green energy project (COP-21) on the world. With this reason, we have first removed the invalided technologies from the established FL tubes.

II. Invalided Technologies in Study on FL Tube

The advanced coil-EEFL tubes cannot produce with (a) the existing production facilities of the FL tubes, and (b) the quality of the commercial phosphor powders. All of them for the commercial FL tubes are empirically optimized with the evaluation of the invalided technologies. For the development of the advanced coil-EEFL tube, we must clarify the invalided technologies that have had the established by the hypotheses and misinterpretations of the observed results for more than 80 years [8, 9, 10, 11]. You should wash out all of them from your memory in the brain for the study on the supreme coil-EEFL tubes as the incandescent light source. After the unambiguous elucidations, you will find a large room that remains for the significant improvements in (a) the AC active power consumption,

W_{act}, (b) illuminance (lm m^{-2}) of the lighted coil-EEFL tubes, and (c) operation life. The clarification items are below:

a) Luminous efficiency (lm W^{-1}) is for study of colorimetry

The largest mistake in the established technologies is the evaluation of the performance of the FL tubes by the luminous efficiency (lm W^{-1}) [3, 4]. The luminous efficiency (lm W^{-1}) is for the study of the colorimetry. It cannot use for other purpose.

Furthermore, the W in the luminous efficiency is the energy of the lights in the visible spectral wavelengths, W_{light}, which is only determined by the bolometer. The scientists and engineers who are studying on the FL tubes never measure W_{light}. They take the W_{act} that is the active power consumption of the external AC deriving circuit. The W_{act} is not related with the generation energy of the light of the FL tubes; $W_{light} \neq W_{act}$. They deliberately had another mistake for the determination of the W_{act}. They actually determined the W_{tube} as the W_{act}. The details of W_{act} and W_{tube} will be later in 2-6. The reported luminous efficiency of the FL tubes is actually given by the (lm W_{tube}^{-1}). This is the serious error in the study on the FL tubes. The light sources should be evaluated with either the luminance (cd m^{-2}) or illuminance (lm m^{-2}) and irradiance (W m^{-2}), which are determined by the Ulbricht Sphere [12]. The W in the irradiance is made with the bolometer that the spectral sensitivity adjusts to the visible lights by the eyes. The irradiance is not use in the evaluation of the practical FL tubes.

Followings are the simple evidence with the evaluation of the FL tubes by the erroneous luminous efficiency (lm W_{tube}^{-1}). The W_{tube} decreases with Ar gas pressures. The compact 10W-HCFL tubes that were made in China widely spread on the US market on 1995. The 10W-HCFL tubes made in China were produced with the Ar gas pressure at 133 Pa (= 1 Torr) for the increase in their luminous efficiency (lm W_{tube}^{-1}). But the operation life is shortened by the rapid evaporation of the heated bear metal spot of the W-filament coil by the irradiation of the accelerated electron beam from the 4G electron source [13]. The compact 10W-HCFL tubes had lost the credibility from the USA customers with the short operation life (< 500 hours) before 2005. The recovery of the once lost credibility from the customers is a very hard.

Recently, we have found the acceptable compact 12W-HCFL tubes on the market in China. The actual AC power consumption is W_{act} = 20 watt. The compact 20W_{act}-HCFL tubes, which are produced with the Ar gas pressure at 10^3 Pa ($\approx$ 7 Torr), have the illuminance (6000 lm, m^{-2}) with the corrected Ulbricht sphere. The single compact-20W-HCFL tube illuminates the 20 m^2 room with the illuminance (300 lm, m^{-2}) with the operation life longer than 10^4 hours [12].

b) FL tube is not discharge lamp

The FL tubes had named as the "FL discharge lamp" [3, 4, 5]. Accordingly, the commercial FL tubes are named as the FL discharge lamps. Practical FL tubes are not the discharge lamp. The moving electrons in the FL tubes are well controlled by the electric field between the cathode and anode of the internal DC electric power generator [8]. The FL tubes are not the discharge lamp. It is FL tube.

c) No thermoelectron emission from electrode in HCFL tube

The FL tubes use the moving electrons in the Ar gas space. The moving electrons require the electron supplier as cathode and anode collects the electrons. However, the cathode and anode in the HCFL tubes is made with the hypothesis [3, 4, 5] without a proof scientifically. Consequently, the HCFL tubes are the nominal HCFL tubes. The scientists never studied the thermoelectron emission from the heated BaO particles.

The drilled studies on the thermoelectron emission from the heated BaO layers into the vacuum had made with the development of the cathode-ray tubes (CRT) and vacuum (radio) tubes that belong to the vacuum physics. The Ba atoms arranged at top layer on the heated BaO layers on the metal cathode steadily emit the thermoelectrons into the vacuum at the pressures lower than 10^{-4} Pa (< 10^{-7} Torr). The thermoelectron emission is below 2 x 10^{-3} A. The BaO particles never emit the thermoelectrons and never collect the electrons from the vacuum. The electrically conductive electrode as the anode in CRT and vacuum tubes collects arrived electrons from the vacuum. The operation condition of the devices is the DC electric circuit.

There is a strict limitation of the thermoelectron emission from the heated Ba atoms on the BaO layers in the vacuum pressures. The heated Ba atoms on the BaO layers do not emit the thermoelectrons into the vacuum at the pressures higher than 0.1 Pa (> 10^{-3} Torr). The Ba atoms on the BaO layers instantly change to the BaO particles that are electric insulator in the poor vacuum. The FL tube always contains the Ar gas pressures higher than 133 Pa (> 1 Torr) with the large amount of the residual gases including the air. The BaO particles on the W-filament coils in the lighted FL tubes are the electric insulators. The hypothesis of the thermoelectron emission in the HCFL tubes is invalided by the drilled study on CRTs and vacuum tubes.

By the erroneous hypothesis, many commercial HCFL tubes use the twisted W-filament coils with the expectation of the increase of the thermoelectron emission from the heated BaO particles on the W-filament coils. They believe that the light intensity from the FL tubes relates with the numbers of the injected thermoelectrons from the BaO particles. However, they never observed the working electrodes under the optical microscope. Figure 5 shows photograph, as the evidence, of the twisted W-filament coils of the commercial HCFL tubes. Figure 6 shows photograph of the heated W-filament coils in a given FL tube under the optical microscope (x 5). The heated areas of the W-filament coil are assigned as the bear metal coil at nearby BaO particles. The BaO particles on the large area of the W-filament coils do not heat up to the working temperature in the lighting HCFL tube.

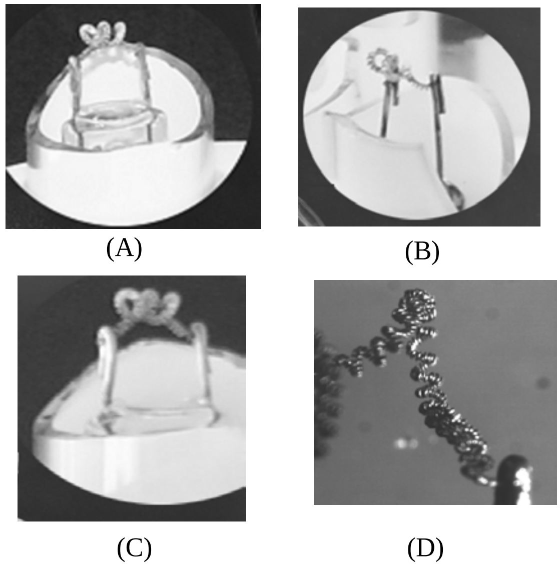


Figure 5 : Photographs of twisted W-filament coils with BaO particles in commercial FL tubes

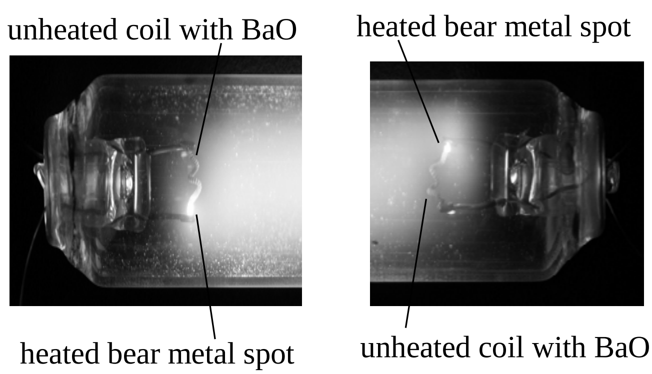


Figure 6 : Photographs of working W-filament coil with BaO particles in lighted FL tube

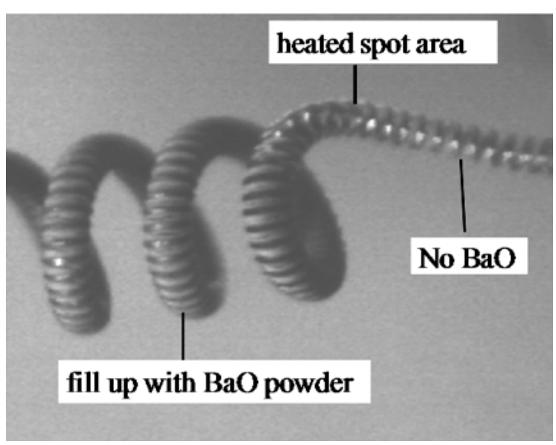


Figure 7 : photograph of ideal W-filament coil with BaO particles

Figure 7 shows photograph of the ideal W-filament coil with the BaO particles for the FL tubes. The ideal W-filament coils always have the bear metal coil in some length at the end of the coil. The heated area of the working W-filament coil is assigned as the bear metal coil at nearby the BaO particles as noted in Figure 7. The W-filament coil of the densely packed BaO particles and the long W-filament coil without the BaO particles do not heat up in the working FL tube. The bear metal spot of the W-filament coil heats up by the irradiation of the electrons from the 4G electron source for each half cycle of the external AC driving device [13]. The bear metal spot does not heat up by the electrons from the 4G electron source for subsequent half cycle. The unheated bear metal spot cools down with the high thermal conductance of W-filament coil for the subsequent half cycle. The BaO particles have the large heat capacity. The heated BaO particles at nearby heated bear metal spot actually hold the temperature for the subsequent half cycle. So far as the W-filament coils are operated with the external DC electric circuit, the bear metal spot on the W-filament coils continuously heats, resulting in the rapid evaporation of the heated W-filament. The continuous evaporation gives rise to the short operation life of HCFL tube; less than 100 hours. The real electron sources of the lighted HCFL tubes are the 4G electron source [13]. The 4G electron sources are formed by the heated volume of the ionized Ar atoms on the heated spot on the W-filament coil. The demerit of the 4G electron source is short operation life with the evaporation of the heated spot of the W-filament coil; maximum operation life is around 10^4 hours.

As described above, the BaO particles on the W-filament coil never emits electrons into the Ar gas space and never collects the electrons from the Ar gas space. Accordingly, the electrodes of the lighted FL tubes never close with the moving electrons. The electrodes of the nominal HCFL tube do not closed with the electron flow. The Ar gas space allows the electron flow of 2 x 10^{-4} A maximum. Above the 5 x 10^{-4} A, the electrons become the arc current [8]. The electrodes of the nominal HCFL tube are actually closed with the induced AC current from the capacitor C_{tube}. The electrodes of the FL tubes detect the induced AC current at between 0.1 A and 1 A, depending on the numbers of Ar^{1+} in the lighted FL tube. The detected AC induced currents is not relate with the moving electrons in the Ar gas space. The thermoelectron emission from the heated BaO particles on the W-filament coils is an illusion in your brain.

d) No AC current waveform on screen of oscilloscope

The operations of the lighted FL tubes under the AC electric current have supported by the report on "waveform of AC lamp current" detected at the electrodes of the AC driving circuit of the lighted FL tubes [3, 4]. This is the misinterpretation of the detected waveform on the screen of the oscilloscope by the reporters who have the ignorance of the waveform of the capacitor. In reality, the oscilloscope does not have current sensor. The oscilloscope has only voltage sensor. The waveforms in the lead wire detect the voltage changes between the electrodes of the inserted small resistance, a few Ω.

The study on the waveforms of the lighted HCFL tubes should be detected at the everywhere of the components of the AC driving circuit for the comprehension of the electric current in the AC driving circuit. Figure 8 shows the voltage waveforms on the screen of the oscilloscope that have determined at everywhere of the driving circuit of the commercial 40W-HCFL tube with the ballast (chock coil). The waveforms have determined at the electrodes of the inserted 10 Ω resistance. You may detect the sine wave at everywhere in the driving circuit, except for the electrodes of the HCFL tube that has assigned as the waveform of the "AC lamp current". This is the wrong assignment.

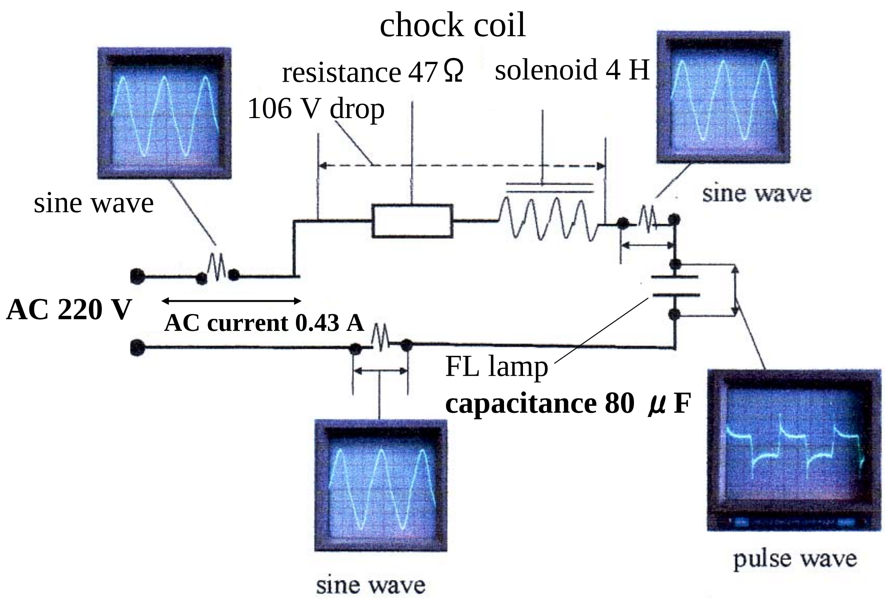


Figure 8 : Waveforms at positions in working driving circuit of FL tube with AC driving circuit

The waveform detected at the electrodes of the FL tube is not the waveform of the AC lamp current in the Ar gas space. It is the waveform of the change in the voltages at the electrodes of the capacitor C_{tube} [14]. We must have a good understanding of the physics of the C_{tube} of the lighted HCFL tube. The waveform of the C_{tube} consists of the sharp transient pulse and constant voltage for residual time. The transient time corresponds to the displacement time of the distribution of the electrons in the inside of the Ar^{1+}. The transition period is 0.5 ms with the commercial FL tubes. The constant voltage in the detected waveform corresponds to the voltage by the displaced electrons in the Ar^{1+}. The transition period of 0.5 ms does not change with the given C_{tube}. If the external AC driving circuit is operated with the frequency higher than 2 kHz $\{= (0.5 \text{ ms})^{-1}\}$, you will surely detect the slightly deformed sine wave at the electrodes.

The sine waveforms at everywhere in the AC driving circuit in Figure 8 surely indicates that the AC driving circuit is apparently shorted at the electrodes of the C_{tube}. The apparently shorted electrodes of the C_{tube} gives the sine wave at the everywhere of the AC driving circuit.

e) Wrong determination of optimal operation temperature at 40°C

It has obstinately believed that the optimal operation temperature of the FL tubes is around 40°C [3, 4]. The FL tube does not have the heating device. The experiments of the determination of the optimal operation temperature of the FL tubes had made in the heated oven. In that time, the phosphor screen of the FL tube was made by the $Ca_3(PO_4)_4$(F, CL):Sb:Mn white emitting PL phosphor particles. The phosphor screen gave the wide gap (4 x 10^{-3} m depth) between positive column and phosphor screen [10, 11]. The Ar gas in the wide gap is the good thermal insulator. Consequently, the gap between positive column and phosphor screen had the large temperature gradient in the heated oven. The experiments in the heated oven gave the apparent optimal temperature of the FL tube at ~ 40°C.

As the FL tubes have the gap shallower than 1 x 10^{-4} m, the illuminance of the phosphor screen increases with the temperatures of the FL tubes to higher than 80°C. Naturally, your FL tubes increase the illuminance (lm m^{-2}) and prolong the operation life to 10^4 hours.

f) Wrong determination of power consumption of FL tubes

Finally, we like to point out the wrong determination of the AC power consumption of the driving circuit of the FL tubes. In the study on the FL tubes, we are facing a difficulty with the determination of the W_{act} of the external AC driving circuit. Many commercial HCFL tubes indicate the 40W-HCFL tubes. The 40W is not the real AC active power consumption, W_{act}, of the external AC driving circuit. The nominal W is a large difference (a half) from the real W_{act}. We must clarify the definition of the W_{act} in the practice.

The AC driving circuits have two different power consumptions; apparent power consumption W_{app}, and active power consumption W_{act}. The AC driving circuits for the FL tubes always contain the impedance. The consumers who use the FL tubes pay their electric bill with the W_{act}, instead of W_{app}. We take the W_{act} in this report.

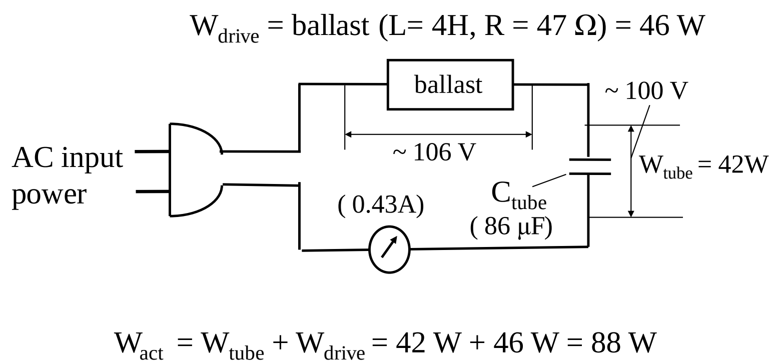


Figure 9 : Schematic explanations of AC driving circuit of FL tube and AC power consumptions of W_{act} that is composed with W_{drive} at ballast and W_{tube} at FL tube

Figure 9 illustrates the determined AC power consumption of the external AC driving circuit of the commercial 40W-HCFL tube with the ballast (choke coil). The FL tube made in China that contains the Ar gas pressure at around 665Pa (= 5 Torr) or less. The AC driving circuit contains two reactance that are (a) inductance composed by chock coil L and electric resistance R, (L + R), and (b) capacitance of the C_{tube} between the electrodes of the FL tube. AC input power is 220 V with 50 Hz. The ordinary electric tester detects the AC current of 0.43 ± 0.05 A at everywhere in the AC circuit. The reactance of the ballast is determined by the ordinal instruments in the laboratory. The ballast is composed with L = 4 H and R = 47 Ω. The reactance of the coil is calculated as 247 Ω. The voltage drop at the ballast is calculated as 106 V (= 247 Ω x 0.43 A) that has confirmed by the ordinal tester. The AC active power consumption of the inductance is calculated as 46 W (= 106 V x 0.43 A) that is the W_{drive}. The capacitance of the C_{tube} in the lighted FL tube cannot determine by the ordinal instrument. The capacitance is calculated from (a) the AC voltage at the electrodes (100V) of the HCFL tube, (b) AC induced current from the electrode (0.43 A) and (c) AC frequency (50 Hz). The reactance of the C_{tube} is calculated as 232 Ω {= 100 V x $(0.43\ A)^{-1}$}. The capacitance that is calculated from reactance is 86 μF {= $(232 \times 50)^{-1}$}. The power consumption of the capacitance is calculated as 43 W (= 100 V x 0.43 A) that is the AC power consumption of the lighted FL tube, W_{tube}.

From Figure 9, the AC driving circuit of the lighted FL tube consists with two different AC power consumptions, W_{drive} and W_{tube}. The W_{act} is composed with sum of them; $W_{act} = W_{drive} + W_{tube}$. The W_{act} is 89 W (= 46 W + 43 W). The electric power consumption of the lighted commercial 40W-HCFL tube is actually 89 W ± 5 W. The 40W-HCFL tube is deliberately assigned with the W = W_{tube} by neglecting of W_{drive}. The 40W of the commercial 40W-HCFL tube is the nominal power consumption. The real W_{act} is given by $W_{drive} + W_{tube}$ = 89 W. The consumers who use the FL tubes as the light source pay their electric bill of the W_{act} that is the double cost of the nominal W = W_{tube}. Recently, the HCFL tubes are operated with the inverter with the frequencies higher than 30 kHz with the reasons of (a) rapid start of the FL tubes and (b) the prolonged operation life to 10^4 hours from 2,000 hours. The W_{drive} of the inverter is a half of the W_{tube}. The W_{act} with the inverter of the nominal 40W-HCFL tube is ≈ 60 W (= W_{drive} + W_{tube}) that is the 1.5 times of the nominal W = W_{tube}.

The Ar gas pressure of the Chinese 40W-HCFL tubes is 665 Pa (= 5 Torr) or less. The HCFL tubes that are produced by other countries have the Ar gas pressure at 931 Pa (= 7 Torr) with the AC induced current at around 0.6 A. The ratio of the Ar gas pressures is 0.71 (= 665 x 931^{-1}) that corresponds to the ratio of the AC induced current of the C_{tube}. The AC currents of the Chinese HCFL tubes is 0.43 A (= 0.6 A x 0.71). As the nominal HCFL tube has the less Ar gas pressures, the bear metal spot in the W-filament coil heats up to the high temperatures, resulting in the short operation life by the evaporation of the bear metal spot. The reduction of the Ar gas pressures comes from the evaluation by the invalided luminous efficiency (lm W_{tube}^{-1}). As described above, the nominal W of the commercial 40W-HCFL tubes is actually the W_{tube}. We must take the real W_{act} for the study on the revised FL tubes.

We cannot use the invalided terms as described above for the study on the advanced FL tubes. Please wash out the invalided terms from your memory in the brain for the study on the advanced FL tubes.

III. Revised Fundamentals of FL Tubes

All electric devices have the metal electrodes as cathode and anode at both ends. The solid electric devices are operated with the anode electrode as electron source and cathode electrode as electron collection source. The vacuum devices are operated with the cathode electrode as electron source and anode electrode as electron collection source. The conditions of the Ar gas space in the FL tube quite differ from solids and vacuum at pressures less than 10^{-5} Pa (< 10^{-7} Torr). The difference of the Ar gas space does not clarify since the invention of the FL tube. The electron source and electron collection source of the FL tubes remain as the ambiguity for the study on the FL tube.

The study on the FL tubes started from the use of the cold cup (CC) electrodes and then switched to the heated W-filament coils with the BaO particles (HC). However, the CC electrodes and HCFL electrodes do not emit the electrons into the Ar gas space [13, 14]. For the clarification of the ambiguity of the electrodes in the Ar gas space, we will use the sharp needle cathode as the electron emitter in the vacuum-sealed glass tube. The glass tubes contain (a) the high vacuum less than 10^{-5} Pa and (b) the Ar gas pressures higher than 1 Pa (> 10^{-2} Torr). The experimental results unambiguously prove the coexistence of the disparities of the external electric driving circuit and the internal electric power generator in Ar gas space in the lighted FL tubes [15]. Then, we will describe the characteristic properties of the moving electrons in the Ar gas space in the vacuum-sealed glass tube. The details are below:

3-a) Electron source and electron collection source in FL tube

Fortunately, we have the sharp needle metal electrodes in our hands. The sharp needle electrode surely emits the electrons in the high vacuum [16] and plat metal electrode collects the electrons from the high vacuum. The preliminary experiments were made with the combination of the needle cathode and the metal plate as anode in the vacuum-sealed glass tube. The experiments were made with the application of the DC voltages to the electrodes. The DC current meter at the needle electrode detects the emitted electrons into the vacuum-sealed glass tube, and the current meter at the plate anode detects the collected electrons from the vacuum in the vacuum-sealed glass tube. Figure 10 illustrates the experimental configuration. The first experiments are made with the glass tube at the vacuum pressure lower than 10^{-5} Pa (< 10^{-7} Torr).

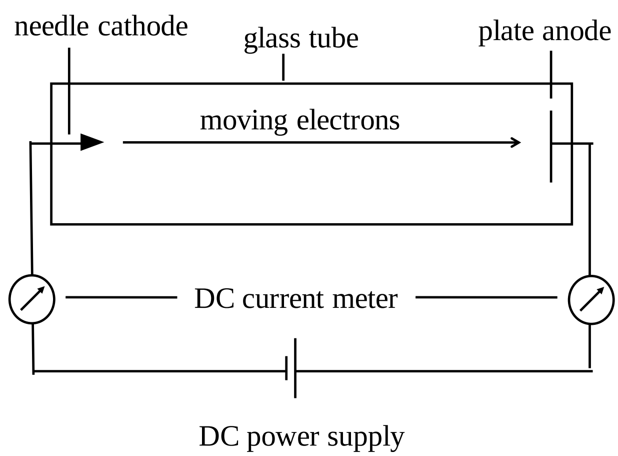


Figure 10 : Explanation of structure of experimental glass tube for electron emission from needle cathode and plate anode under DC power supply

3-a-i) Experiment in vacuum pressure less than 10^{-5} Pa (< 10^{-7} Torr)

As the glass tube has the vacuum pressure less than 10^{-5} Pa (< 10^{-7} Torr), the sharp needle electrode surely emits the electrons into the vacuum as the DC voltage is above 12 V. The threshold voltage changes with the sharpness of the needle electrode. The amount of the emitted electrons into the vacuum is detected by the DC current meters. The detected electron current increases with the applied voltages but the electrodes hold the constant voltage at 12 volt, as shown in Figure 11. The constant voltage at the electrodes with the different electron currents indicates that the moving electrons in the vacuum do not have R. Consequently, the moving electrons do not loss the energy in the vacuum by IR (= V). The vacuum in the glass tube provides the "superconductive vacuum" for the moving electrons. The moving electrons in the high vacuum do not have a chance to meet floating atom, resulting in no lights from the experimental glass tube. A limitation of the electron emission from the needle electrode comes from the R of the needle cathode. The sharp point of the needle metal electrode has the high electron current density at 10^{-6} A. Consequently, the sharp point in the needle metal cathode has the melting temperature by the Joule Heat (I^2R). Consequently, the melted sharp point is rounded. The threshold voltage of the rounded sharp point shifts to the high volts. Then, the vertical current curve slowly bents with the applied voltages, as shown in Figure 11.

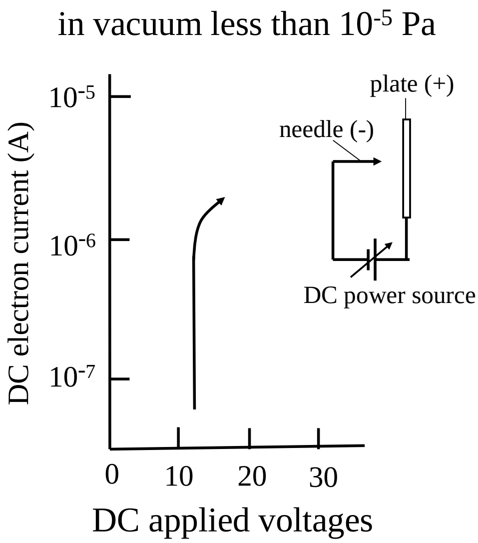


Figure 11 : Experimental curve of DC current between needle electrode and plat anode in vacuum at 10^{-5} Pa

3-a-ii) Experiment in Ar gas pressure at 1 Pa and higher

As the glass tube contains the Ar gas at the pressure 1 Pa (> 10^{-2} Torr), the needle cathode at 100V does not emit the electrons into the Ar gas space. The conditions of the Ar gas in the glass tube totally differ from the high vacuum. The different conditions with the Ar gas may find the absorption spectrum of the Ar atoms by the high resolution spectrometer. The absorption spectrum informs us followings.

The absorption spectrum consists with the sharp lines as far as the Ar atoms floating in Ar gas space do not have the overlapped wave function from neighboring Ar atoms. We have certainly detected the sharp absorption lines in the spectrum. However, the numbers of the detected absorption lines are much higher than the inherent energy levels of Ar atom. Followings are well known in the analytical chemistry. As the Ar atoms are under the electric field, the inherent energy levels split to the sublevels by the Stark Effect. The measurements of the absorption spectrum certainly inform us the followings. Although each Ar atom floats in the vacuum without the overlapped wave function from neighboring Ar atoms, the vacuum between Ar atoms is filled with the negative electric field from the orbital electrons of neighboring Ar atoms.

The Ar atoms in the vacuum at 10^4 Pa (= 75 Torr) do not have (a) the overlapped wave function from neighboring Ar atoms. However, (b) the negative electric field from the neighboring Ar atoms fills up in the vacuum between Ar atoms. The results are the new information of the study on the Ar gas space of the unlighted FL tube. The electrons from the sharp point of the needle cathode receive the Coulomb's repulsion from the negative field in the vacuum between Ar atoms, so that the electrons from the sharp point of the needle cathode cannot step in the Ar gas space. Figure 12 illustrates the negative electric field in vacuum between Ar atoms.

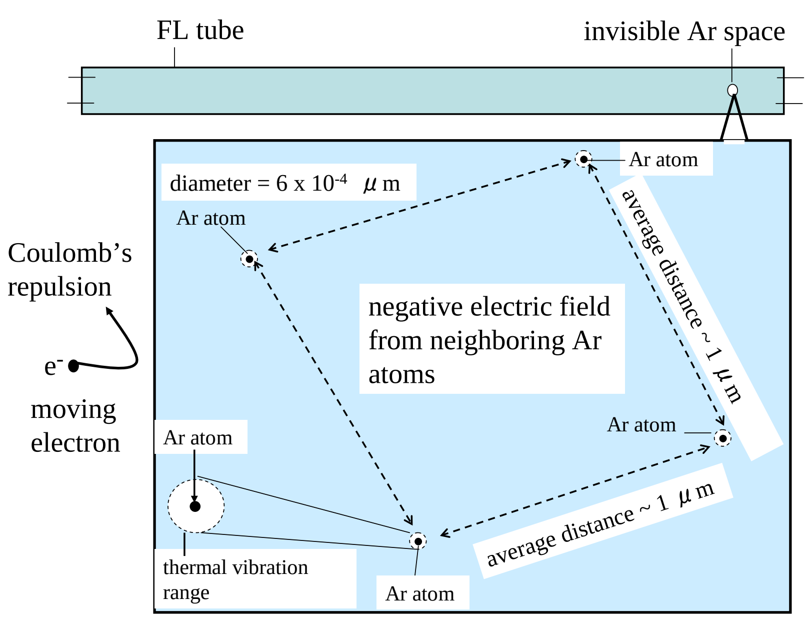


Figure 12 : Schematic illustration of vacuum between Ar atoms that fills up negative electric field from neighboring Ar atoms in Ar gas space in unlighted glass tube

As the DC voltage of the needle electrode gradually increases, the glass tube suddenly light up with the sky-blue light at 1 kV. The accelerated electrons under the vector electric field, F_{vect}, (= 1 keV) may break the negative electric field in the vacuum between Ar atoms. The reality may differ from the statement above.

Global Journal of Science Frontier Research (A) Volume XV Issue VIII Version I Year 2015

The needle cathode electrode looks like to be covered with the volume of the sky-blue light. We have a question whether the start of the lighting of the Ar atoms is not made by the direct injection of the electrons from the sharp point of the needle electrode or not. Then we have following experiments.

Figure 13 illustrates the experimental configurations. When the anode disconnects from the DC power supply, the lighting of the entire area of the Ar gas disappears from the glass tube. Then, we have observed the volume of the sky-blue light around the needle cathode as illustrated in Figure 13 (A). The diameter of the volume of the glow light on the needle cathode is 3 x 10^{-3} m, independent on the applied voltages to the needle cathode above 1 kV. With the curiosity, the similar experiments are made with the needle anode. The needle anode is also covered with the same size of the volume of the glow light. Figure 13 (B) illustrates the needle anode is covered with the volume of the glow light. The glow light never appears on the plate anode.

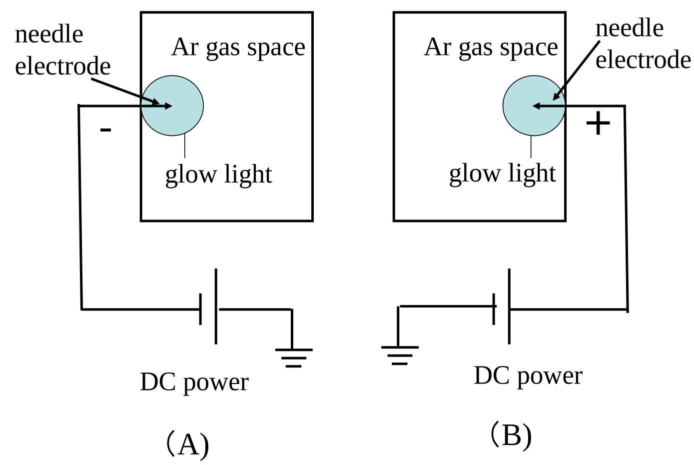


Figure 13 : Schematic illustration of volumes of glow light on needle cathode (A) and needle anode (B)

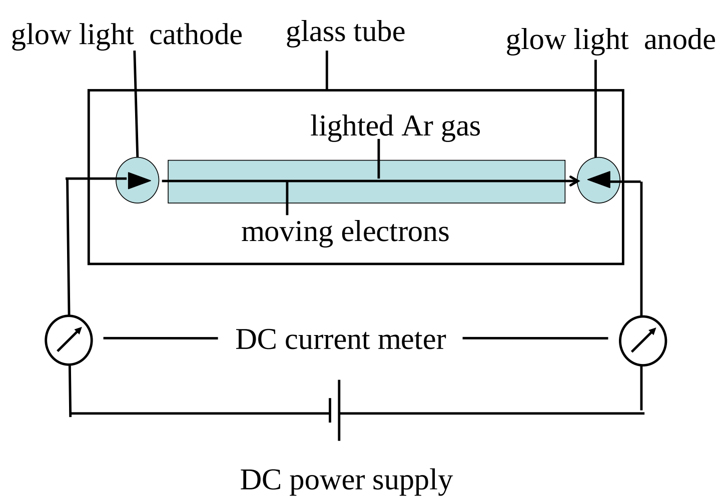


Figure 14 : Schematic illustration of lighted column of Ar atoms between volumes of the glow light on needle cathode electrode and needle anode electrode

When the glass tubes have the needle cathode and anode, the glass tubes emit line-like sky-blue light between needle cathode and anode with the diameter of about 3 x 10^{-3} m as illustrated in Figure 14. From the observations of the results in Figure 13, the volumes of the glow lights on the needle cathode and anode respectively work as the new cathode and anode in the lighting glass tube, instead of the sharp point of the needle cathode and anode. The findings of the cathode and anode by the volumes of the glow light reveal the presence of the internal DC electric power generator in the Ar gas space in the lighted glass tube.

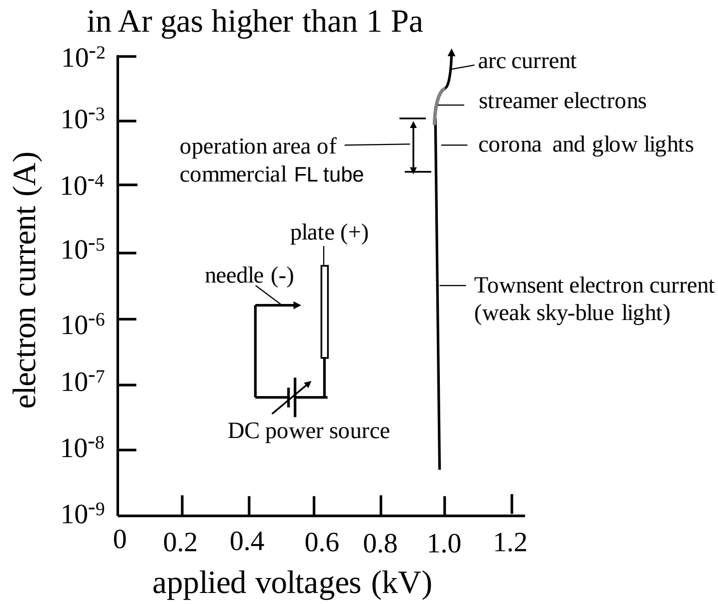


Figure 15 : Experimental curve of DC current between needle electrode and plat anode in Ar gas pressures at 10 Pa

As the applied DC voltage gradually increases from 1 kV, the DC current between needle cathode and anode vertically increases up to 10^{-3} A, as shown in Figure 15. The needle cathode and anode hold the constant voltage at 1 kV with the electric current up to 10^{-3} A. The DC current meters at the needle metal electrodes surely supply the electrons to the volume of the glow light up to 10^{-3} A. However, the needle electrode holds the sharp point with the electron current at 10^{-3} A. The sharp point of the needle cathode may acts as the trigger of the formation of the volume of the glow light. The sharp point of the needle electrode works no longer as the electron supplier into the Ar gas space in the volume of the glow lights. The entire area of the needle cathode supplies the electrons to the volume of the glow lights. Therefore, the sharp point of the needle electrode does not round with the high electron current at 10^{-3} A. This is the wonderful advantage for the needle cathode in the Ar gas space. In the Ar gas, the volumes of the glow lights on the needle cathode and anode act as the cathode and anode of the internal DC electric power generator. The diameter of the volumes of the new cathode and anode determines the diameter of the lighting column in the glass tube.

We must understand the reasons that the volume of the glow light becomes the electron source in the glass tube. The volume of the glow light on the needle cathode and anode is made by the ionization of Ar atoms by the electric field from the sharp point of the needle electrodes. The electric field from the sharp point of the needle electrode triggers the ionization of the Ar atoms at nearby the sharp point. The ionized Ar atoms (Ar^{1+}) neutralize the negative field between Ar atoms. The electric field from the needle cathode may gradually attenuate with the distance from the metal electrode by the presence of the Ar^{1+}. The attenuation of the negative electric field from the needle electrode may determine the amount of the Ar^{1+} in the volume of the glow light. If it is so, the glow lights on the needle cathode limit the constant volume with the different applied voltages to the negative needle electrode. We have fund that the volumes of the glow lights at the needle electrodes form the cathode and anode of the internal DC electric power generator in the Ar gas space. The further details of the scientific study on this subject remains for the future study.

The majority of the particles in the volume of the glow light are the ionized Ar atoms (Ar^{1+}) and free electrons. The minority is the excited Ar atoms (Ar*). Ar^{1+} and electrons are invisible particles by the naked eyes. Only minor Ar* emits the sky-blue lights at 435 nm that are visible light by the naked eyes. We may use the sky-blue light as the monitor for the presence of the volume of the glow light.

In the volume of the glow light, the ratio of the numbers of Ar^{1+} to Ar* is around 10 to 1. The volume of the glow light contains a large amount of Ar^{1+}. The presence of the Ar^{1+} may completely neutralize the negative electric field in the volume of the glow light. The weight of Ar^{1+} and Ar* is 1.7×10^{-27} kg and the weight of electron is 9.1×10^{-31} kg. As the volume of glow light is under the F_{vect}, the electrons move on with 10^4 times faster than Ar^{1+}. Consequently, we have a conclusion that the majority of the moving particles in the volume of the glow light are the free electrons under the F_{vect}.

The electrons in the volume of the glow light are accelerated by the F_{vect}. The accelerated electrons by the F_{vect} may step out from the volume of the glow light.

Global Journal of Science Frontier Research (A) Volume XV Issue VIII Version I Year 2015

The stepped-out electrons from the volume may ionize the Ar atoms at nearby the volume of the glow light. The ionized Ar^{1+} neutralizes the negative electric field at nearby the volume of the glow light. The neutralization of the negative field in the vacuum propagates to the entire Ar gas space to the anode in the glass tube with the speed of the moving electrons. The moving speed of the electrons in the Ar gas space is estimated around 10^5 m per second [4, 5]. After a moment of the formation of the volume of the glow lights on the needle cathode, one may observe the instant lighting of the entire volume of the lighting column in the glass tube by the sky-blue light. The diameters of the volume of the glow light may determine the diameter of the lighting column in the Ar gas space. The diameter of the 4G electron sources extends to the inner diameter of the FL tube with the length at around 1×10^{-2} m that gives 7.0×10^{-6} m^3. The volume of the glow lights on the needle electrodes is the sphere with the diameter of 1×10^{-3} m that gives 1.4×10^{-8} m^3. The volume of the 4G electron source is 500 times $\{= 7.0 \times 10^{-6} \times (1.4 \times 10^{-8})^{-1}\}$ of the volume of the glow light on the needle electrode. The calculated results suggest us that the volume of the glow light on the single needle electrode is not large enough for the practical FL tubes. Anyhow, the fundamental properties of the volume of the glow light do not change with the size of the volume of the glow light.

It should note that the glass tube lights up with the sky-blue light at the low DC current at 10^{-6} A. The light intensity increases with the electron current in Figure 15. The increase in the sky-blue light is caused with the increase in the numbers of the moving electrons in the vacuum-sealed glass tube. At the given electric current, the light intensity increases with the Ar gas pressure. The increase in the light intensity is caused by the increase of the probability of the excitation of the Ar atoms by the moving electrons between cathode and anode of the internal DC electric power generator.

As the summary, the electron source and electron collection source in the lighted glass tubes are substantially the volumes of the glow light which are formed in the Ar gas. The volumes of the glow light form the cathode and anode of the internal DC electric power generator in the Ar gas space. The diameter of the volume of the glow light is 3×10^{-4} m, independent on the Ar gas pressures. The electrons move on in Ar gas space from the volume of the glow light on the needle cathode metal to the volume of the glow light on the needle anode metal. The lighting conditions of the studied glass tubes are the same with the FL tubes, except for the phosphor screen and Hg vapor. After here, we call the glass tube as the FL tubes.

3-b) Superconductive vacuum between Ar atoms for moving electrons

The electrons move on in Ar gas space from the volume of the glow light on the needle cathode metal to the volume of the glow light on the needle anode metal. The results in Figure 15 provide us important information of the study on the moving electrons in the Ar gas space of the FL tubes. By the referring of the vertical curve of the electric current in the high vacuum shown in Figure 11, the vertical curve of the electric current up to 10^{-3} A in Figure 15 informs us followings. The vacuum between Ar atoms in the lighted FL tube is the superconductive vacuum for the moving electrons in the Ar gas space up to the moving electrons of 10^{-3} A. The moving electrons do not disturb by the thermal perturbation from the neighboring Ar atoms that are thermally vibrating of the Ar atoms at the floating position. We do not consider the electric resistance, R, for the moving electrons in the Ar gas space of the lighted FL tubes. The moving electrons in the superconductive vacuum never lose the kinetic energy by R. Figure 16 illustrates the moving electrons in the superconductive vacuum between Ar atoms. The moving electrons do not have the thermal perturbation from the vibrating neighbor Ar atoms.

Global Journal of Science Frontier Research (A) Volume XV Issue VIII Version I Year 2015

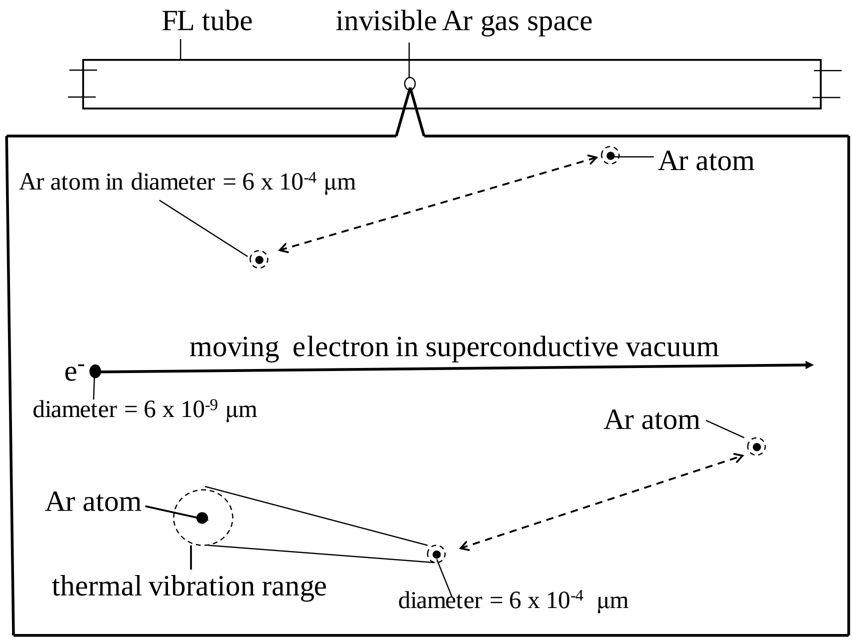


Figure 16 : Schematic explanation of superconductive vacuum between Ar atoms for moving electrons from needle cathode to anode in lighted glass tube. Moving electrons do not have electric resistance by thermal perturbation of neighboring Ar atoms

As described above, the vacuum between Ar atoms is quietly wider vacuum space as compared with the narrow vacuum in the solids. We do not consider R for the moving electrons of the lighted FL tube at the temperatures up to 80°C and more high. If someone claims the existence of R by the decrease in the lighting intensity with the distance from the cathode, it is not caused by the R. It is caused by the vertical electric field from the phosphor screen, F_{phos} [10, 11]. The diameter of the positive column decreases with the distance from the cathode with the reason that the kinetic energy of the moving electrons decreases with the distance from the cathode. The decrease of the kinetic energy may eliminate by the control of the F_{phos} as described in the development of the coil-EEFL tube in latter. Anyway, the superconductive vacuum for the moving electrons in the FL tube is the remarkable advantage over the solid-lighting lamps.

There is the maximum electron current for the superconductive vacuum between Ar atoms. Above 1 x 10^{-3} A, the moving electrons gather up in the Ar gas space to form the electron beam that is the streamer electron current. Above 5 x 10^{-3} A, the moving electrons become the arc current. The formation of the streamer electron current and arc current is not change with the volumes of the glow light. We must use the below 1 x 10^{-3} A for the study on the FL tube. The curve in Figure 15 does not change with the Ar gas pressures up to 10^4 Pa (~ 70 Torr) that we have examined.

The commercial FL tubes at the present time are produced with the Ar gas pressure less than 10^3 Pa (< 7 Torr). The electrons in the FL tubes move on in the "superconductive vacuum" between floating Ar atoms as illustrated in Figure 16. Here is a problem. The Ar gases in the present FL tubes are heavily contaminated with the residual gases, especially the inverse diffusion of the contaminated oil vapor from the diffusion pump and rotary pump. By the contamination of the oil vapors, the maximum electron current of the present FL tubes is not 1 x 10^{-3} A. The electron current with the contaminated Ar gases reduces to around 4 x 10^{-4} A (= 2 x 10^{15} electrons per second). The established pumping facilities of the FL production are heavily contaminated with the decomposed pumping oil. With this reason, we take the moving electrons at 4 x 10^{-4} A in the following calculations.

It should note that the residual gases in the vacuum-sealed FL tubes predominantly come from the maintenance and handling of (a) diffusion pumps, and (b) rotary pumps. The air in the working rooms is heavily polluted with the PM 2.5 particles and more large particles, inorganic and organic gases, water vapor, and dusts in μm sizes. The diffusion pump never operates for the pumping out of the room air, even if the pump producers claim the safe operation of the room air. Their claim is not true. The oil of the diffusion pump is surely and gradually contaminated with the pollutants in the room air. The diffusion pumps only use in the vacuum pressures below 0.1 Pa (< 10^{-3} Torr). The vacuum-sealed FL tubes and total vacuum systems at present time in Asian countries are heavily contaminated with the inverse diffusion of the contaminated oil of the diffusion pump and the rotary pump. This is also said to the production of the CRTs.

3-c) η_q of moving electron in superconductive vacuum of FL tube

As already mentioned before, the figure of the merit of the incandescent lamps is the quantum efficiency η_q. We may calculate the η_q of the lighted FL tube. The lights from FL tubes are originated from the excitation of the Hg atoms in the Ar gas space. As the Hg atoms are excited by the moving electrons, the excited Hg atoms (Hg*) emit the short ultraviolet (UV) light at 254 nm by the electron transition from the excited state 6^3p_1 to grand state 6^1s_0 of the Hg atom. The UV light is invisible by the naked eyes. The phosphor screen transduces the invisible UV lights to the lights in the visible spectral wavelengths with the $\eta_q \approx 1.0$. Accordingly, the numbers of the visible photons from the phosphor screens in the FL tubes correspond to the numbers of the UV photons on the phosphor screen. The η_q of the FL tube is calculated by the numbers of the Hg* $(m^3, s)^{-1}$ by one moving electron in the FL tube. The electron under the F_{vect} moves on in the superconductive vacuum between cathode and anode, without the Joule Heat. The moving electron has a chance to meet floating Ar (and Hg) atoms in the vacuum. The numbers of the Hg atoms in the Ar gas space of the commercial HCFL tubes is around 10^{-3} times of the Ar atoms. First, we will calculate the numbers of the Ar* by one moving electron in the Ar gas space $(m^3, s)^{-1}$.

Ar atoms randomly float in vacuum with the Maxwell-Boltzmann distribution. The electron from the cathode has the probability to meet the randomly floating Ar atoms in the vacuum. The moving electron cannot get in the orbital shell of the Ar atom. The moving electron receives the strong Coulomb's repulsion from the orbital electrons of the Ar atom. The repulsed electron to the vacuum is the scattered electron from the longitudinal F_{vect}. The repulsed electron from the Ar atom gives some kinetic energy to the electron in the upper orbital shell of the Ar atom. The orbital electron that has received the kinetic energy rises up to the upper energy level of the Ar atoms. As the received energy is higher than the ionization energy (> 15.7 eV) of the Ar atom, the Ar atoms are ionized by the release of one electron to the vacuum. The ionized Ar atom is Ar^{1+}. The scattered electron in the vacuum stays in the superconductive vacuum and takes again the longitudinal F_{vect} in the Ar gas space in which $F_{vect} \geq F_{orb}$. Then, the scattered electron meets other Ar atom and ionizes it, as illustrated in Figure 17. The moving electron gradually attenuates the kinetic energy by each Coulomb's repulsion from the Ar atom. As the moving electron has attenuated to the kinetic energy between 15.6 and 11.5 eV, the moving electron excites the Ar atom (Ar*). As the attenuated kinetic energy is below 11.4 eV, the moving electron recombines with Ar^{1+}. The Ar^{1+} returns to Ar atom as illustrated in Figure 18. Consequently, the specified moving electron disappears from the Ar gas space.

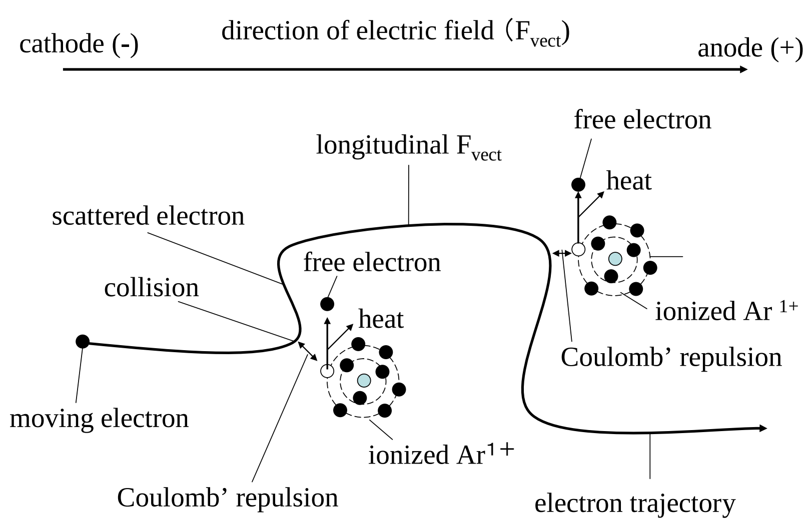


Figure 17 : Schematic explanation of trajectory of moving electron with Coulomb's repulsion and longitudinal acceleration by F_{vect} in vacuum

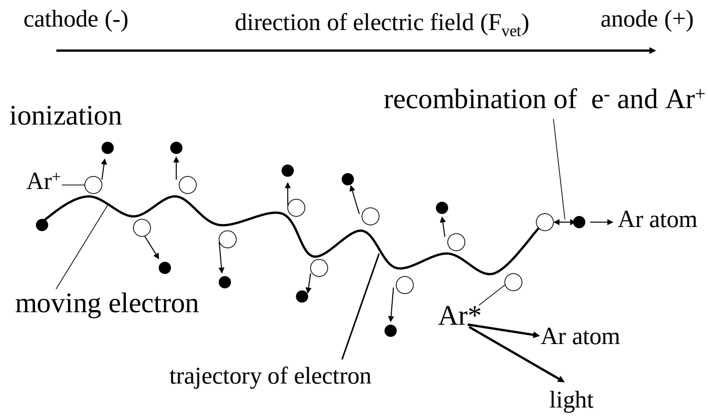


Figure 18 : Schematic illustration of trajectory of moving electron in superconductive vacuum in FL tube

Although the individual moving electrons recombine with the Ar^{1+} in the process of the longitudinal movement as illustrated in Figure 18, the same numbers of the moving electrons exist in the Ar gas space by the generated free electrons from the ionization of Ar atoms. Statistically, the same numbers of the electrons continuously move on in the superconductive vacuum in the Ar gas space under the F_{vect}. This is supported by the fact in the experiments in Figure 15. The Ar gas in the glass tube emits the sky-blue light by the excitation of the Ar atoms by the moving electrons, holding the vertical curve up to 10^{-3} A. The numbers of the injected electrons from the needle cathode coincides with the numbers of the collected electrons by the anode. Therefore, we may take one moving electron from the cathode to the anode as the statistical calculations. It is not by the specified electron in the Ar gas space. Statistically, the 10^{18} Ar atoms per m^3 and 4×10^{15} electrons per unit time exist in the Ar gas space of the lighted FL tube.

We may quantitatively calculate the numbers of the Ar* per m^3 of the Ar gas space per second in the lighted FL tubes. The calculated η_q is 10^{16} Ar* $(m^3, s)^{-1}$ [17]. The numbers of the Hg atoms in the Ar gas space is 10^{-3} times of the numbers of Ar atoms. The numbers of the Hg* in the Ar gas space is calculated by the 10^{-3} times of the excited Ar*. The η_q of the Hg* by one moving electron is given by $\eta_q = 10^{13}$ Hg* $(m^3, s)^{-1}$. Each Hg* emits one UV photon and return to Ar atom. The phosphor screen transduces the UV photons to the visible photons with $\eta_q \approx 1.0$. The calculated η_q of the emitted visible photons from the phosphor screen in the FL tube is the astronomical numbers as $\eta_q = 10^{13}$ visible photons $(m^3, s)^{-1}$. The η_q of the FL tube ever reported in the study on the FL tube [3, 4, 5]. We may confirm the calculated results with the numbers of the emitted photons from the phosphor screen of the commercial 40W-HCFL tube.

The numbers of the moving electrons in the Ar gas space of the lighted 40W-HCFL tube is 2×10^{15} electrons per second $\{= 4 \times 10^{-4}$ A x $(1.6 \times 10^{-19}$ Coulomb$)^{-1}\}$. 1 A is 1.0 Coulomb per second. The phosphor screen of the 40W-HCFL tube may emit the 2×10^{28} visible photons $(m^3, s)^{-1}$ $(= 1 \times 10^{13} \times 2 \times 10^{15})$. The volume of the commercial 40W-HCFL tube (T-10) in 1 m long is 5×10^{-4} m^3. Accordingly, the commercial 40W-HCFL tube emit the 1×10^{25} visible photons $(= 2 \times 10^{28} \times 5 \times 10^{-4}$ visible photons per tube) per second. The commercial 40W-HCFL tube may illuminate the surface of the furniture in 1 m^2 room with the daytime scenery under the slightly overcastting sky. Thus, we have unambiguously proved the performance of the commercial 40W-HCFL tube with the astronomical $\eta_q = 10^{13}$ visible photons $(m^3, s)^{-1}$ in the FL tube. The η_q is determined by the moving electrons between cathode and anode of the internal DC electric power generator and is not given by the W_{act} of the external AC driving circuit.

3-d) Cut off electron flow between needle electrode and volume of glow light

The needle cathode supplies the electrons to the volume of the glow light and the needle anode collects the electrons from the volume of the glow lights. Consequently, the DC driving circuit consumes 0.4 watt $(= 2 \times 10^3$ V x 2×10^{-4} A) of the DC power consumption. We have the experiments for the removal of the electric power consumption of the DC driving circuit of the lighted glass tube.

The surfaces of the needle cathode and anode are covered with the thin layer of the frit glass that is the electric insulator. The frit glass layer blocks the electron flow from the needle metal electrode to the volume of the glow light. The threshold voltage for the formation of the volume of the glow light does not change with the layers of the frit glass on the needle electrodes. By the application of DC 4 kV to the needle electrodes, the glass tube brilliantly light up with the sky-blue light, nevertheless the DC current meters at the needle electrode show zero electric current. The volume of the glow light is formed without the supplement of the electrons from the needle cathode and collection of the electrons by the needle anode. We have experimentally succeeded the formation of the isolated internal DC electric power generator in the Ar gas space in the glass tube. Details are below:

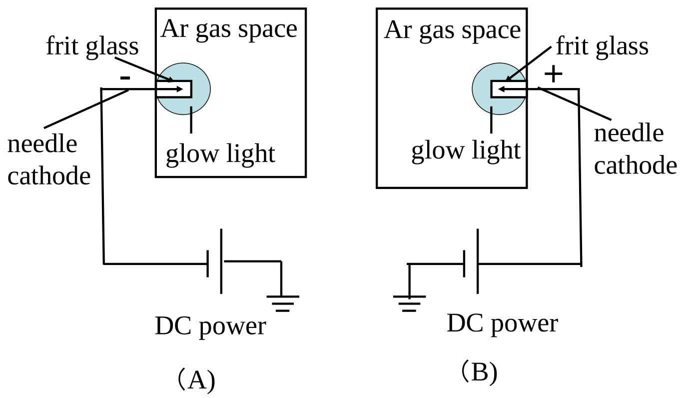


Figure 19 : Schematic illustration of volumes of glow light on frit glass layers that cover on needle cathode (A) and needle anode (B)

The frit glass layers of the electric insulators completely prevent the electron flow from the needle electrodes to the volume of the glow light. For the confirmation of the volumes of the glow light on the needle electrodes, we have the similar experiments with Figure 13. In this time, the needle electrodes are covered with the frit glass layer. Figure 19 illustrates the experimental configurations. The volumes of the glow light surely form on the frit glass layer that covers the needle electrodes. The diameter of the volume of the glow light on the frit glass layer is the same with and without the frit glass layer. Hence, we have found the formation of the cathode and anode of the electrically isolated internal DC electric power generator in the Ar gas space from the external driving circuit. The formation mechanisms of the volume of the glow light on the frit glass insulator are below:

The frit glass layers are the electric insulator but the glass layer may polarize under the electric field from the metal electrodes. Then the polarized charges in the frit glass may have the electric field to the Ar gas space. The Ar gas space under the electric field from the polarized frit glass generates the volume of the glow lights in the same size with the volume on needle metal electrodes. This is a moment that we have discovered the generation of the volumes of the glow light in the Ar gas space without the electric power consumption of the driving device. Figure 20 schematically illustrates the details of the formation mechanisms of the volume of the glow light at around the polarized frit glass layer. The Ar^{1+} and electrons do not uniformly distribute in the volume of the glow light on the polarized frit glass layer. The large amount of Ar^{1+} and electrons separately distributes in the volume of the glow light under the electric field from the polarized frit glass layer. The separated distribution respectively forms ΣAr^{1+} and Σe in the volume of the glow lights. The ΣAr^{1+} and Σe in the volume of the glow light respectively act as the substantial cathode and anode of the isolated internal DC electric power generator in the Ar gas space.

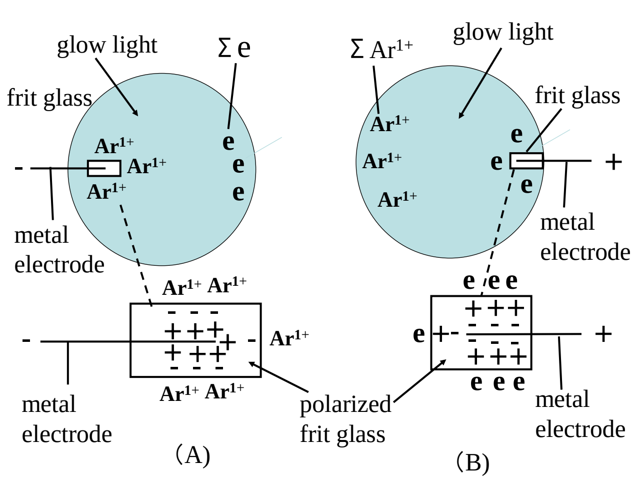
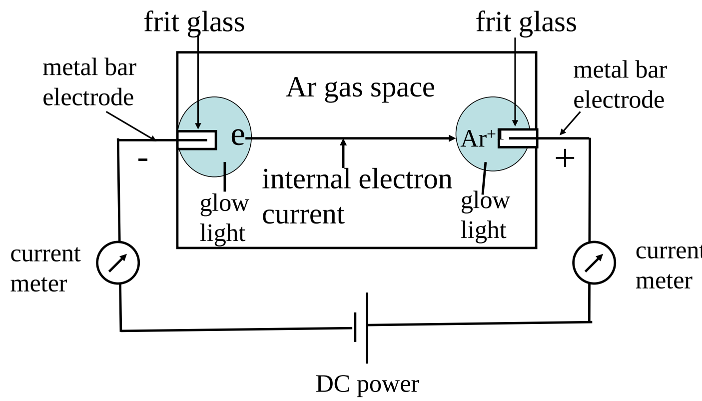


Figure 20 : Formation mechanisms of volume of glow lights on polarized frit glass layers that cover on needle cathode (A) and needle anode (B)



$$e + Ar^{1+} \longrightarrow Ar \ \ \text{(recombination)}$$

Figure 21 : Explanation of moving electrons between volumes of glow light as cathode and anode of internal DC electric power generator formed in Ar gas space

The glass tube brilliantly emits the sky-blue light in the Ar gas space between the cathode (Σe) and anode (ΣAr^{1+}) of the internal DC electric power generator. The brilliant lights surely indicate the electrons flow from the cathode to the anode of the internal DC electric generator as shown in Figure 21. Nevertheless the glass tube brilliantly lights up, the DC current meters at the needle metal electrodes do not show any electron current from the needle metal electrodes. Hence, we have confirmed that the lights are generated by the moving electrons between the cathode and anode of the internal DC electric power generator that is formed in the Ar gas space under the electric field of the polarized frit glass.

Then, we have the additional experiments. As the testing glass tube, that the needle electrodes are covered with the frit glass layers, the threshold voltage of the lighting of the Ar atoms is 1 kV_{rms}. The light intensities of the Ar atoms are the same with the DC and AC operation. A significant difference exists in the operation by the DC and the AC driving circuits. The electrodes of the DC electric circuit have no electric current that is zero.

On the other hand, the electrodes of the AC driving circuit have the large AC current at 0.03 A. This is because the needle electrodes vertically set on in the glass tube. So far as the metal electrodes vertically set on the glass tube, the metal electrodes certainly pick up the induced AC current from the capacitor C_{tube} from the Ar^{1+} in the glass tube [17]. There are two kinds of the capacitors. One is the capacitor by the frit glass layer, C_{frit}. Other is the capacitor by the C_{tube}. The capacitance of the C_{frit} is a small as compared with the capacitance of the C_{tube}. The C_{frit} does not change with the Ar gas pressures and the length of the lighted glass tube. In contrast with the C_{frit}, the capacitances of the C_{tube} linearly change with (a) with the lighting lengths and (b) volume of the glass tubes. Accordingly, the AC current at the electrodes of the C_{tube} linearly increases with (i) the Ar gas pressures in the constant volume of the glass tube, and (ii) the volumes of the glass tube at the constant Ar gas pressure. For instance, the AC current of the electrodes of the tested glass tube is 0.03 A with the Ar gas pressures at 665 Pa (= 5 Torr). The AC current is 0.3 A with the Ar gas pressures at 6.6 x 10^3 Pa (= 50 Torr). If the glass tube has the gas pressure less than 10^{-1} Pa (< 10^{-4} Torr), the glass tubes do not light up under the DC and AC driving circuit. Accordingly, the AC current is zero with the reason that there is no C_{tube} with the low Ar gas pressures. The AC current in the AC driving circuit is caused by the induced AC current from the capacitor C_{tube} in the lighted glass tube.

The testing glass tubes under the operation of the AC driving circuit, we have following information. The internal DC electric power generator on the frit glass layer on the needle electrodes synchronously alternate the positions of the cathode and anode in the Ar gas space under the cycles of the AC driving devices. The alternative switching time is the half cycle of the applied AC cycles. For example, the alternative switching cycles of the AC driving cycle are 10 ms with 50 Hz and 170 μs $\{= 1 \times (3 \times 10^{-3} \times 2)^{-1}\}$ with 30 kHz. The internal DC electric power generator periodically and rapidly changes the positions of the cathode and anode in the Ar gas space for each half cycles of the AC driving circuit.

From the observations described above, it may say that the W-filament coils in the commercial HCFL tubes vertically set against the longitudinal FL tube. Naturally, the W-filament coils pick up the large AC induced current; e.g., 0.5 A. It is not by the electron flow from the Ar gas space. The lights from the HCFL tubes are generated by the moving electrons between the 4G electron sources formed in the Ar gas space that are a kind of the volumes of the glow light [13]. The commercial HCFL tubes inevitably require the heated

Global Journal of Science Frontier Research (A) Volume XV Issue VIII Version I Year 2015

spot at the W-filament coil with the BaO particles [13]. The HCFL tube can be operated with the DC driving circuit with $W_{DC} = 0$. But the DC operation life of the HCFL tube is less than 100 hours by the continuous evaporation of the heated bear metal spot of the W-filament coil. The HCFL tube should be operated with the AC driving circuit with the high frequencies as possible for the operation life longer than 10^3 hours. The mixed-up of the electron flow and the induced AC electric current was the main reason that the reporters of the FL tubes had a logical leap in the analysis of the operation mechanisms of the HCFL tubes in the past.

3-e) Coexistence of disparities of electric circuits in lighted glass tube

According to Figure 22, the internal DC electric power generator by the volumes of the glow light is certainly formed in the Ar gas space in the glass tube, notwithstanding no electron flows from the needle electrodes. The volumes of the glow lights on the polarized frit glass layers respectively act as the cathode and anode of the internal DC electric power generator formed in the Ar gas. The volume of the glow light as the cathode emits the electrons into the Ar gas space, and the volume of the glow light as the anode corrects the electrons from the Ar gas space. The arrived electrons to the anode recombine with the Ar^{1+} and returns to Ar atom. The Ar atoms reserve in the operation of the internal DC electric power generator. The reservation of the Ar atoms in the operation of the glass tube promises the prolonged operation life of the internal DC electric power generator. Thus, we have unambiguously proved the coexistence of the disparities of the internal DC electric circuit and the external AC electric circuit in the operation of the glass tubes. The structure of the studied glass tube is fundamentally same with the FL tube, except for the electrodes, the Hg atoms and phosphor screen in the Ar gas.

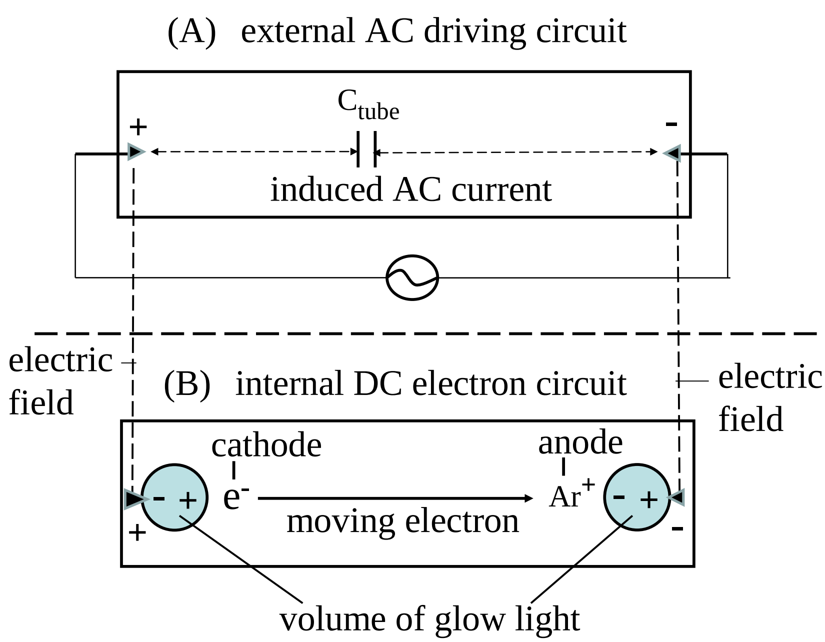


Figure 22 : Schematic explanation of electric closeness of AC driving circuit by AC induced current from C_{tube} (A) and moving electrons from cathode to anode of internal DC electric power generator that is formed in Ar gas space without electron flow from external AC driving circuit (B)

The examined glass tubes can be operated with the external AC driving circuit, as already described. Figure 23 illustrates the coexistence of disparities of electric circuits in lighted glass tube. Figure 23 (A) illustrates the electric closeness of the external AC driving circuit by the induced AC current from the C_{tube}. Figure 23 (B) illustrates the moving electrons from the cathode to anode of the internal DC electric power generator in the Ar gas space. As illustrated in Figure 23 (A), the induced AC current never involve in the generation of the lights of the FL tubes. The lights in the glass tubes are surely generated by the moving electrons from the cathode to the anode of the internal DC electric power generator in the Ar gas space. There is no electron flow between disparate two circuits as illustrated in Figure 22. Consequently, the generation of the lights from the glass tubes must study the moving electrons from the cathode to the anode of the internal DC electric power generator in the Ar gas space of the glass tube.

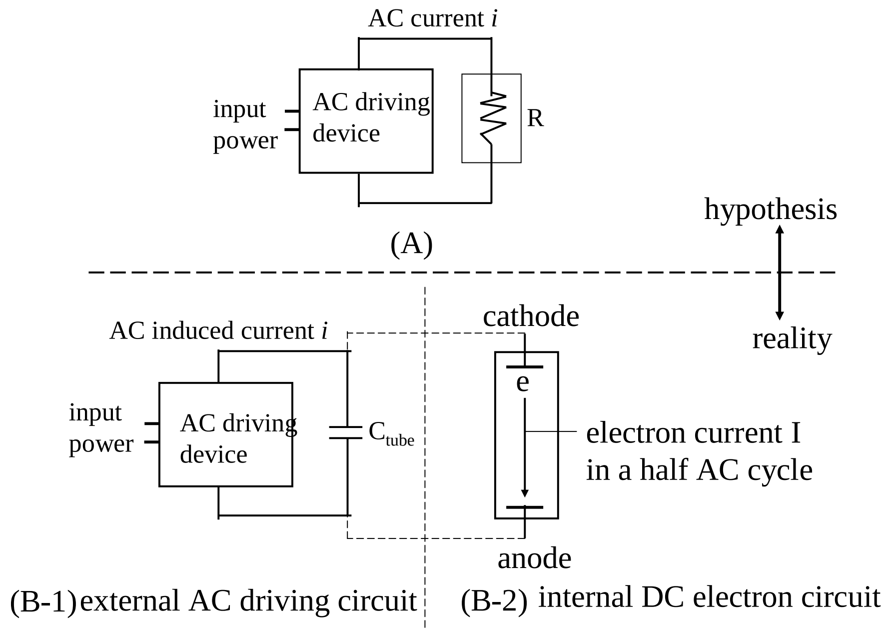


Figure 23 : Schematic explanation of traditional electric circuit by hypotheses (A) and coexistence of disparities of external AC driving circuit and internal DC electron circuit in lighted FL tube

We may apply the results of the glass tubes to the FL tubes. The characteristic properties of the FL tubes containing Ar gas should be analyzed with the coexistence of the disparities of the internal DC electric circuit and external AC (or DC) driving circuit. Figure 23 illustrates (A) the reported hypotheses in the past and (B) the coexistence of the disparities of the internal DC electric circuit and external AC driving circuit in the lighted FL tubes.

IV. Development of Prototype of Coil-EEFL Tube

As described above, the lighting mechanisms of the incandescent FL tubes totally differ from the lighting mechanisms of the incandescent LEDs and metal filament lamps. The FL tubes use (a) the vacuum between Ar atoms that float with the 1 x 10^{-6} m separation distance. (b) The vacuum between Ar atoms is superconductive vacuum for the moving electrons. (c) The internal DC electric power generator is formed in the Ar gas space by the volumes of the glow light as the cathode and anode. (d) The lights are generated by the moving electrons between cathode and anode of the internal DC electric power generator in the Ar gas space. And (e) the active power consumption, W_{act}, of the external AC driving circuit is not related with the generation of the lights from the nominal HCFL tubes.

The volume of the glow light on the needle electrode as the cathode and anode is 1.4 x 10^{-8} m^3 with the diameter of 3 x 10^{-3} m. The nominal HCFL tubes use the 4G electron source that also uses the glow light with the large volume of 7.0 x 10^{-6} m^3 = (3 x 10^{-2} m diameter with 1 x 10^{-2} m long) [13] that is 500 times of the volume of the glow light. The demerits of the 4G electrons source are the short operation life with the external DC driving circuit, shorter than 100 hours. For the long operation life for 10^4 hours, the nominal HCFL tubes should be operated with the external AC driving circuit. Then, the external AC driving circuit inevitably has the large W_{act} that does not relate to the energy of the generation of the lights from the nominal HCFL tubes.

We have found the large rooms remain for the improvement of the performance of the FL tubes with (a) the nearly zero power consumption, (b) high illuminance (lm, m^{-2}) or luminance (cd, m^{-2}), and (c) prolonged operation life to longer than 10^6 hours. As the FL tube is operated with 24 hours per day, 1 year is 8.7 x 10^3 hours. 100 years are ≈ 10^6 hours. As already mentioned, the most attractive subject of the incandescent FL lamps is the reduction of the unnecessary W_{act} of the external AC driving circuit. We have found the final target that is the development of the coil-EEFL tubes under the external DC electric circuit that gives W_{DC} = 0. The details are below:

4-a) Preliminary study on coil EEFL tube

The single needle electrode as the cathode is not large enough for the practical FL tubes. The practical FL tubes may require a large numbers of the needle electrodes. We should find the large numbers of the sharp needle electrodes in the practical FL tubes. The phosphor particles may have the sharp line-edges and sharp points with the controls of the production conditions [18]. Then we take our attention to the polarized phosphor particles under the electric field.

4-a-i) Formation of internal DC electron power generator in FL tube

The phosphor screen is made with the polycrystalline phosphor particles that are the unsymmetrical crystals for the high transition probability of the excited luminescent centers. The unsymmetrical particles smoothly polarize under the electric field. The phosphor screens of the commercial FL tubes are produced with the layers of the PL phosphor powders of the average size around 5 x 10^{-6} m. The top layer of the phosphor screen in 1 x 10^{-3} m^2 arranges 2 x 10^5 particles. If the phosphor particles on the top layer of the limited phosphor screen are polarized, the phosphor screen in FL tube may have the needle electrodes more than 2 x 10^5 in the FL tube.

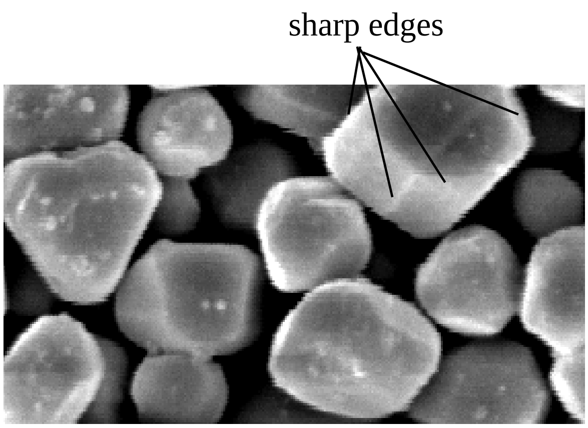


Figure 24 : Photograph of SEM (x 3000) of ideal phosphor particles having sharp edge-lines and points for phosphor screen in coil-EEFL tube

The polycrystalline phosphor particles contain many growing axes. Each phosphor particle has many sharp edge-lines and sharp points. Figure 24 shows photograph of the SEM (x 3000) of the phosphor particles. If the phosphor powders are produced with the ideal conditions [18], the ideal phosphor particles have many sharp edge-lines and corner points, and the surfaces of the phosphor particles have no contamination. The sizes of the sharp edges and sharp corner points are less than 10^{-7} m that is sharp enough as the needle electrodes. If the phosphor particles shown in Figure 24 arranged at the top layer of the phosphor screen in the FL tube, the polarized phosphor particles may have the capability of the formation of the internal DC electric power generator in the Ar gas space under the electric field from the electrode on the outer glass wall.

With the expectation, we have examined with the commercial 40W-HCFL tube. The both ends of the out glass wall of a commercial HCFL tube (T-10) with 1.2 m long are covered with the lead wire (1 x 10^{-4} m diameter with plastic cover) with a few turns that are the external electrodes, EEs. We did not have the DC power source at that time. We used the AC power source of 2 kV_{rms}, 30 kHz. The coil-EEFL tubes certainly emitted the light between EEs on the outside wall of the glass tube with the external AC driving circuit at 2 kV_{rms}, 30 kHz. The W_{coil} of the AC driving circuit was 18 watt that is 30 % of the original HCFL tube (60 W_{act}). The W_{coil} does not change with the position of the EEs on the glass wall from 1 x 10^{-2} m to 1.1 m. The results certainly indicate that the EEs do not pick up the induced AC current from the C_{tube} by the Ar^{1+} that always presence in the lighted Ar gas space. The lighted coil-EEFL tube certainly proves the formation of the internal DC electric power generator in the Ar gas space on the polarized phosphor particles in the phosphor screen. However, the illuminance (lm, m^{-2}) is a low, about half of the commercial FL tubes. The low illuminance may be caused by (a) the electrons selectively move on in the defined volume under the F_{vect} between the cathode and anode of the volume of the glow lights, (b) the low Ar gas pressure (665 Pa = 5 Torr), (c) wide diameter of the FL tube, and (d) wide gap between positive column and phosphor screen. The total thickness of the glow light on the phosphor screen is 6 x 10^{-3} m (=3 x 10^{-3} m x 2) that is one fifth of 3 x 10^{-2} m of the commercial HCFL tube. The coil-EEFL tubes should be made with the narrow FL tube at the Ar gas pressures higher than 6.6 x 10^3 Pa (> 50 Torr).

We have found the commercial 16W-CCFL tubes in the diameter of 3 x 10^{-3} m (T-1) with 4 x 10^{-2} m long, and have the Ar gas pressures at 6.6 x 10^3 Pa (= 50 Torr) from Taiwan. We have converted it to the coil-EEFL tubes. The coil-EEFL tube emits the same illuminance with the original CCFL tube with the same AC driving circuit of 2 kV, 30 kHz. The W_{coil} of the tested coil-EEFL tube reduces to 4.5 W that is 28 % of the W_{act} of the original CCFL tube (16 W). The reduction rate of the W_{coil} of the coil-EEFL tube converted from the CCFL tube is the same with the W_{coil} of the converted from the 40W-HCFL tube. The results indicate the accuracy of the experiments. The position of the EEs changes on the outer glass wall from a 3 x 10^{-2} m to the 3.5 x 10^{-1} m of the coil-EEFL tube. The phosphor screen between the EEs holds the same brightness. We detect no change in the W_{coil} with the lighting length. Hence, we have proved that the EEs of the coil-EEFL tube do not pick up the AC induced current from the C_{tube}, even if the Ar^{1+} presence in the lighting coil-EEFL tube. The original CCFL tube certainly pick up the AC induced current from the C_{tube} that gives the W_{act} = 16 watt. However, the lights from the phosphor screen in the tested CCFL tubes are generated with the moving electrons from the cathode and anode of the internal DC electric power generator in the Ar gas space. To make a confirmation, we have next experiments.

We change the driving circuit to the external DC electric circuit that has output of DC 2 kV for the confirmation of the internal DC electric power generator. The coil-EEFL tube under the DC driving circuit lights up with the same illuminance with the AC driving circuit with V_{rms} = 2 kV. The difference is no DC current in the external DC driving device; i.e., W_{DC} = 0. We have the success of the preliminary experiments of our target with the coil-EEFL tube under the DC external operation. Figure 25 shows photograph of the lighted coil-EEFL tube under the DC electric circuit at 2 kV.

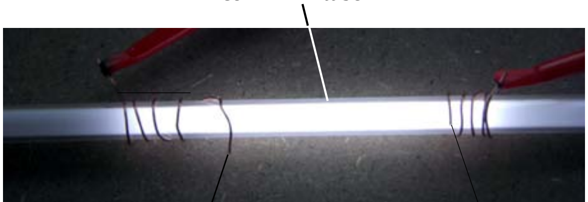


Figure 25 : Photograph of prototype of lighted coil-EEFL tube under 2 kV of DC driving circuit

We surely produce the internal DC electric power generator in the Ar gas space by the volume of the glow light on the sharp edges and sharp points of the polarized phosphor particles on the inner wall of the FL tube. The numbers of the polarized phosphor particles under the EEs on the outer glass wall of the FL tube corresponds to the wide 5 x 10^{-5} m^2. The illuminance of the phosphor screen changes with the numbers of the turns of the lead wire below 5 turns. The EEs above 5 turns, the illuminance of the coil-EEFL tube does not change with the numbers of the turns of the lead wire.

The internal DC electric power generator is surely formed with the volume of the glow light on the polarized phosphor particles. The thickness of the volume of the glow light on the polarized phosphor screen is 3 x 10^{-3} m. Total thickness of the volume of the glow light on the phosphor screen in the coil-EEFL tube should be 6 x 10^{-3} m. As the inner volume of the Ar gas on the phosphor screen fills with the glow light, the coil-EEFL tubes have the advantage with the high illuminance. As the consideration of the scattering of the moving electrons by the Ar atoms, the total thickness may slightly increase the diameters of the applicable coil-EEFL tubes. The optimal outer diameter of the practical coil-EEFL tubes will be between 9.5 x 10^{-3} m (T-3) and 12.7 x 10^{-3} m (T-4). The experiments remain with the future study with the reason that (1) we cannot find the adequate FL tubes from the commercial market, (2) we cannot find the adequate production facilities in China, and (3) we do not find the adequate phosphor powder from the phosphor market on the world.

4-a-ii) Requirement of phosphor particles for coil-EEFL tube

The preparation of the coil-EEFL tube requests the severe conditions on the phosphor screen. Figure 26 illustrates the electric fields from the EE (F_{EE}) on outer glass wall to perpendicular (vertical) direction against the glass wall, and the longitudinal (horizontal) direction in the phosphor screen. In the coil-EEFL tubes, the volume of the Ar gas space has neither the counter electrode nor ground electrode. The phosphor particles in the screen receive the electric field from the EEs and do not have any other electric field. The electric field from the EE on glass wall strongly restricts to the vertical direction, and does not extend to the longitudinal (horizontal) direction in the glass wall and in the phosphor screen as illustrated in Figure 26. The EEs have the anisotropic electric field (F_{EE}) to the vertical direction. The anisotropic F_{EE} exclusively polarizes the phosphor particles that are arranged in the vertical direction against the glass wall. Here is a problem. The EEs strongly restrict the numbers of the layers of phosphor particles less than 5 layers, preferably 3 layers. If the phosphor screen is made with the layers higher than 5 layers, the phosphor particles at the top layer of the phosphor screen does not polarized by the electric field from the EEs. The volume of the glow lights only forms in front of the polarized phosphor particles. Figure 27 shows the SEM photographs of the cross-section of the phosphor screens. Above phosphor screen in Figure 27 is adequate layers for the coil-EEFL tube. If the coil-EEFL tube is produced with the thick phosphor screen in Figure 27 (below), the performance of the coil-EEFL tubes is a poor, and sometime does not light up, depending on the used phosphor powders. The advanced screening technology of the phosphor powder of the FL tube requires for the production of the coil-EEFL tubes. The thickness of the phosphor screens gives a very hard condition to the scientists and engineers who have studied on the HCFL tubes with the established handbooks [19].

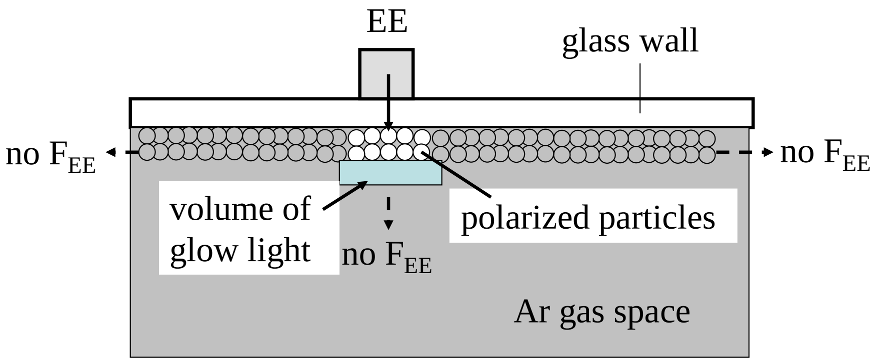
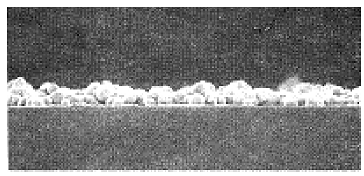
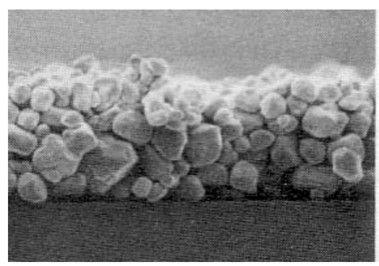


Figure 26 : Schematic illustration of anisotropic electric field of EE on phosphor particles and Ar gas space



(A) ideal phosphor screen



(B) inadequate phosphor screen

Figure 27 : Photograph of SEM picture of cross-section of ideal phosphor screen (A) and inadequate phosphor screen (B) for coil-EEFL tube

The phosphor particles of the coil-EEFL tubes do not sandwich with the electrodes. The electric field from the EEs affects only one side of the phosphor particles and other side of the phosphor particles expose on the Ar gas space. With the lighted coil-EEFL tube, the electric field from the EEs and the electric field of the polarized phosphor particles are electrically shielded by the electric charges in the volume of the glow light. Consequently, the electric fields from the EEs and polarized phosphor particles isolate from the localized electric field in the Ar gas space of the lighted coil-EEFL tube. The electrical shielding by the volume of the glow light is the advantage of the coil-EEFL tubes in the operation.

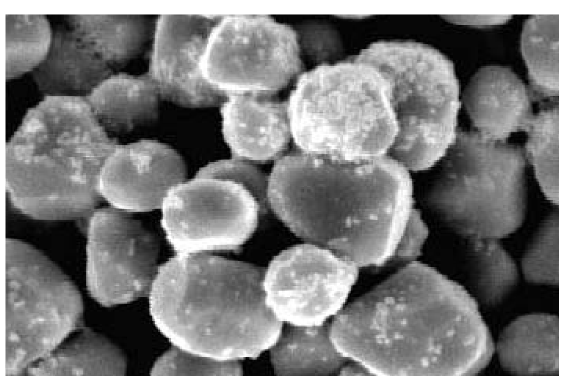


Figure 28 : Photograph of SEM of commercial PL phosphor particles that surfaces are contaminated with impurities of electric insulator and that have less-sharp edges and points

The phosphor particles arranged at the top layer in the screen should have the clean surface chemically and physically. The phosphor particles shown in Figure 24 are acceptable phosphor particles, not the best one. We cannot find the best phosphor particles from the commercial phosphor powders. The surfaces of the commercial phosphor particles are heavily contaminated with (a) the layers of the residuals of the raw materials and (b) attached microclusters. Figure 28 shows SEM photograph of the phosphor particles of many commercial phosphor powders. The particles are the nearly rounded particles that luck of the sharp-edges and sharp points. Beside the shapes of the particles, the surface of the phosphor particles are heavily contaminated with the SiO_2 microclusters [19]. Furthermore, the commercial PL phosphor powders contain the adhesive powers neither (a) (0.7BaO, 0.3CaO) 1.5 B_2O_3, nor (b) CaP_2O_7, (c) mixture of (0.7BaO, 0.3CaO) 1.5 B_2O_3 and CaP_2O_7, and (d) γ-Al_2O_3 [19]. If the surface of the phosphor particles is contaminated with the layer of the electric insulator or the attached microclusters of the electric insulator, the threshold voltage shifts to a high voltage. You never use the commercial PL phosphor powders like as the particles shown in Figure 28 to the phosphor screen of the coil-EEFL tubes.

4-a-iii) External DC and AC operation of coil-EEFL tube

Figure 29 shows photograph of the lighted coil-EEFL tube (above) and lighting mechanism of the coil-EEFL tube by the moving electrons from the cathode to the anode of the internal DC electric power generator in the Ar gas space (below). The external DC driving circuit supplies 4 kV (= 2 kV and 2 kV) between the cathode and anode. The center of the two DC power supply has the grand. The electric power consumption of the external DC driving circuit is $W_{DC} = 0$.

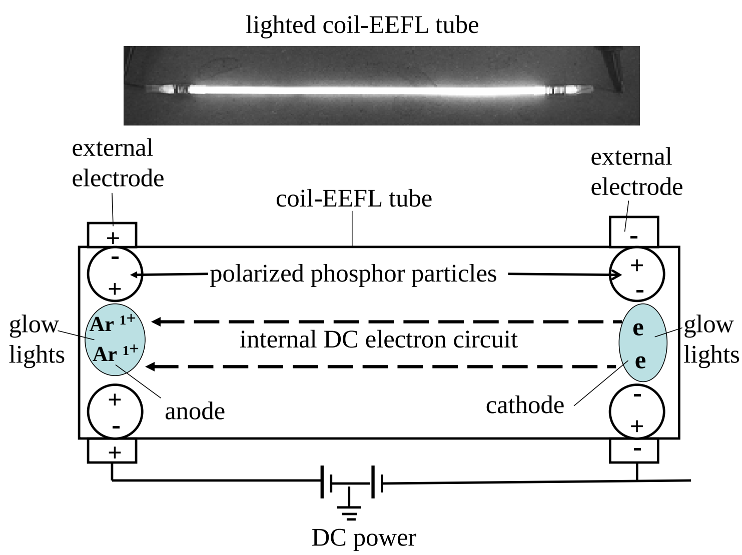


Figure 29 : Photograph of lighted coil-EEFL tube (above) and explanation of moving electrons from cathode to anode of internal DC electric power generator in Ar gas space

If the same coil-EEFL tube is operated with the external AC driving circuit, the AC driving circuit has the induced AC current based on the capacitor C_{phos}. The phosphor particles under the EEs form the C_{phos} by the phosphor particles. The capacitance of the C_{phos} is less than one-third of the capacitance of the C_{tube}. The coil-EEFL tubes do not pick up the capacitance of the C_{tube}, even it is in the lighted coil-EEFL tube. Consequently, the induced AC current in the AC driving circuit of the coil-EEFL tubes does not change with the Ar gas pressures and distance of the EEs on the FL tubes.

The illuminance (lm, m^{-2}) of the coil-EEFL tube under the external DC and AC driving circuits linearly increases with the Ar gas pressures. This is because the temperatures of the positive column only change with the Ar gas pressures. As the positive column has the high temperatures, the positive column contains the large amount of the evaporated Hg atoms from the heated Hg droplets on the phosphor screen. The practical coil-EEFL tubes are produced with the Ar gas pressure less than 9.3 x 10^3 Pa ($\approx$ 70 Torr) with the reason of the heat radiation from the coil-EEFL tubes.

The power consumption of the external DC driving circuit for the lighted coil-EEFL tubes is zero. The recommended DC power supply can be made with the piezoelectric transformers. The design of the external DC electric driving circuit must consider the protection from the transit pulse voltage for 0.5 ms at the turn-on of the power switch.

4-b) Optimization of light output from coil-EEFL tubes

The lights of the FL tubes originate from the excitation of the Hg atoms in the Ar gas space. The excitation of the Hg atoms is made by the moving electrons in the superconductive vacuum between Ar atoms. There are three factors that control of the numbers of the excited Hg atoms in the positive column; one is the diameter of the positive column, next is the optical absorption of the UV light from the positive column by the unexcited Hg atoms in the Ar gas space in the gap, and third is the temperature of the Ar gas space in the positive column. The diameters of the positive column in the FL tube in the given outer diameter change with the vertical electric field from the phosphor screen, F_{phos}. First, we will describe about the F_{phos}.

4-b-i) Electric charges on phosphor particles control performance of FL tube

The F_{phos} restrict the volume of the positive column in which electrons move on in the Ar gas space in the FL tube. Naturally, there is the gap between positive column and phosphor screen. The control of the depths of the gap determines the illuminance (lm, m^{-2}) of the given FL tubes; especially, the illuminance (lm, m^{-2}) of the coil-EEFL tubes in the narrow outer diameters less than 1.3 x 10^{-2} m (T-3). The required depth of the gap of the coil-EEFL tubes is shallower than 2 x 10^{-4} m.

After light-up of the FL tube, the electrons under the longitudinal F_{vect} move on in the superconductive vacuum between Ar atoms in the FL tube. The diameters of the positive column are severely controlled with the vertical F_{phos} against the longitudinal F_{vect}. The F_{phos} uniformly distribute on the entire phosphor screen. The F_{phos} ever discussed in the study on the FL tubes in the past.

The phosphor screen in the FL tube is not only the transducer from the UV lights to the visible lights, but is also the control of the trajectory of the moving electrons in the Ar gas space in the lighted FL tube. At present, the phosphor producers and FL tube producers pay their attention to merely pinholes and dark spots of the phosphor screen. Then, they empirically found the surface treatments of the phosphor particles for the reduction of the pinholes and dark spots in the phosphor screen. Consequently, the commercial phosphor particles are heavily contaminated with the microclusters of the electric insulators as shown in Figure 28. Their attentions are a minor item with a few % of the illuminance from the phosphor screen of the FL tubes. Main problem that determine the illuminance (lm, m^{-2}) of the FL tubes is the F_{phos} of the phosphor screen.

The electron is the particle that has the negative charge (1.6 x 10^{-19} Coulomb). The diameter of the volume (V_{posi}) of the moving electrons in the Ar gas space is severely restricted by the F_{phos}. As the moving electrons approach to the phosphor screen, the electrons receive the strong Coulomb's repulsion from the F_{phos}. The moving electrons never get in the phosphor screen. Consequently, the electric conductance of the phosphor screen never involves in the lighting mechanisms of the FL tube, which has had been considered [3, 4, 5, 6, 7, 19]. The moving electrons always stay in the Ar gas space in the positive column which is defined as the $F_{vect} \geq F_{phos}$, as illustrated in Figure 30. Accordingly, there is the gap between positive column and phosphor screen which is defined as the $F_{vect} \leq F_{phos}$ in Figure 30.

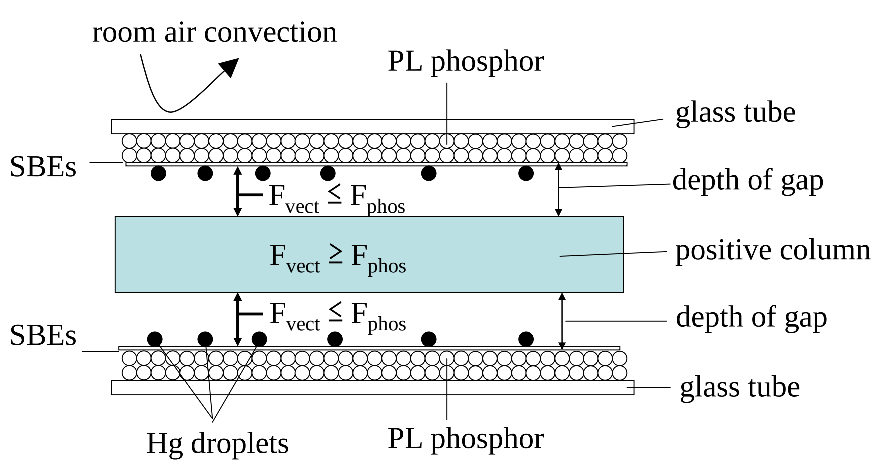


Figure 30 : Schematic explanation of formation of positive column by $F_{vect} \geq F_{phos}$ and gap by $F_{vect} \leq F_{phos}$ and Hg droplets on phosphor screen

The depths of the gap control (a) the amount of the Hg atoms in the positive column and (b) the optical absorption of the UV lights from the positive column before reaching to the phosphor screen. The Hg droplets on the phosphor screen evaporate the Hg atoms into the Ar gas space in the positive column. The heat source for the evaporation of the Hg atoms from the Hg droplets is only the heat radiation from the positive column. The positive column is surrounded with the heat resistance of the Ar gas space, giving rise to the limitation of the Hg evaporation from the Hg droplets on the phosphor screen. Furthermore, the gap contains the large amount of the unexcited Hg atoms, which optically absorb the UV lights from the positive column before reaching to the phosphor screen. Consequently, the illuminance from the FL tubes is severely controlled with the depths of the gap. For instance, as the commercial 40W-HCFL tubes (T-10), that have 4 x 10^{-3} m depth of the gap, reduces to 3 x 10^{-4} m $\{= V_{Ar} \times (V_{posi})^{-1}\}$, the illuminance (lm, m^{-2}) of the commercial 40W-HCFL tubes will goes up 1.8 times. The important subject (F_{phos}) of the study on the FL tubes has remained for us.

It is a better way to show the constant 3 x 10^{-3} m depth of the gap in the different diameters of the commercial FL tubes, which are produced by the current production facilities of the FL tubes. The entire area of the phosphor screens in the lighted commercial FL tubes is uniformly covered with the constant F_{phos} caused by the surface-bund-electrons (SBE) [10]. The depth of the gap from the phosphor screens does not change with the diameters of the FL tubes. On the other hands, the diameters of the positive columns are drastically changed with the inner diameters of the FL tubes. In the study on the reduction of the illuminance (lm, m^{-2}) by the gaps in the FL tubes, it is a better way to take the curves of the $\{(V_{posi}) \times (V_{Ar})^{-1}\}$ as a function of the diameters of the FL glass tube. The parameters are the depths of the gap in the practical FL tubes. Where V_{posi} is the volume of the positive column, and (V_{Ar}) is the volume of the Ar gas in the FL tube. The calculations of the $\{(V_{posi}) \times (V_{Ar})^{-1}\}$ are made with the various diameters of the FL tubes. The parameters of the depths of the gap are 2 x 10^{-4} m and 3 and 4 x 10^{-3} m. Figure 31 shows the calculated results. The ratio of $\{V_{posi} \times (V_{Ar})^{-1}\}$ is nearly saturated with the outer diameters greater than 3 x 10^{-2} m of the FL tubes. The commercial 40W-HCFL tubes with the $Ca_3(PO_4)_4$(F, CL):Sb:Mn white emitting PL phosphor screen have the depth of the gap of 4 x 10^{-3} m. The commercial 40W-HCFL tubes with the tricolor rare-earth phosphor screen have the 3 x 10^{-3} m depth.

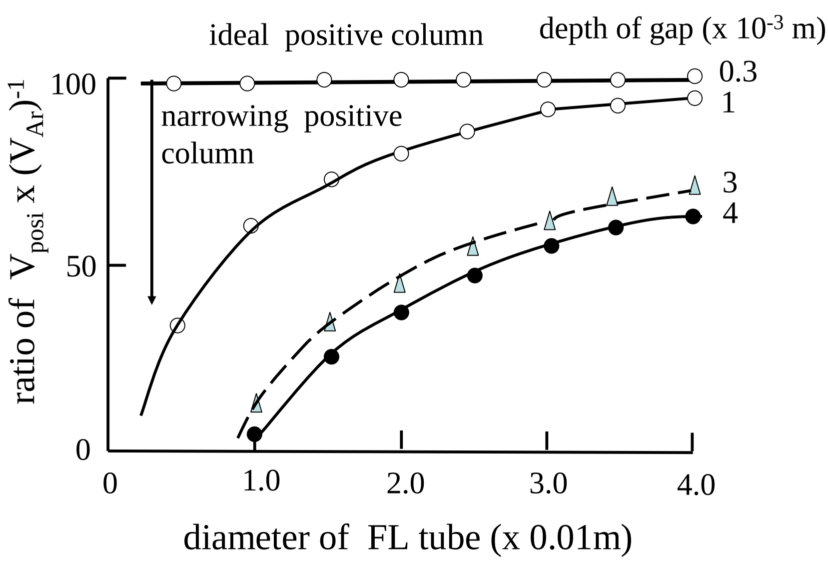


Figure 31 : Curves of $\{V_{posi} \times (V_{Ar})^{-1}\}$ as a function of outer diameters of FL tubes. Parameter is depth of gap

We will describe about the thermal insulation of the positive column by the Ar gas in the gap. The Ar gas is the good thermal insulator; 3.9 x 10^{-7} cal (m, sec. T)$^{-1}$. The positive column in the FL tubes is surrounded with the good thermal insulator of the Ar gas. The Ar gas space in the positive column must contain the large amount of the Hg atoms as possible for the generation of the large amount of the UV lights. The Hg droplets on the phosphor screen must heat up to the higher temperatures as possible for the high illuminance (lm, m^{-2}) of the FL tubes. The heat source in the FL tubes is only the ionization of Ar atoms by the change in the entropy. There is no thermal convection of the Ar gas in the vacuum sealed FL tubes.

The temperature of the phosphor screen on the inner wall of the glass tube is equivalent with the room temperature. The temperature of the positive column instantly heats up to the saturated temperatures within millisecond by the ionization of the Ar atoms. The heat radiation from positive column is only the heat source for the Hg droplets on the phosphor screen. The heating speed of the Hg droplets on the phosphor screen is slow, depending on the depth of the gap. Consequently, the numbers of the evaporated Hg atoms in the positive column slowly increase with the running time, giving rise to the slow build-up curve of the illuminance (lm, m^{-2}) of the FL tube. As the FL tube has the shallow gap, the illuminance from the FL tube rapidly rises up to the higher saturation level. We can monitor the depths of the gap by the measurements of the build-up curve of the illuminance.

The W_{tube} is solely determined by the numbers of the Ar^{1+} in the positive column. The W_{tube} sharply decrease with the narrow outer-diameters of the FL tubes. The Ar atoms in the gap do not involve in the formation of the C_{tube}. But the Ar gas in the gap contains the large amount of the unexcited Hg atoms that optically absorb the UV light from the positive column before reaching to the phosphor screen. The saturated $\{V_{posi} \times (V_{Ar})^{-1}\}$ curve gives the constant ratio of the optical absorption of the UV lights by the unexcited Hg atoms in the gap, giving rise to the constant illuminance. The outer diameter of the nominal 40W-HCFL tubes had empirically determined as 3.2×10^{-2} m (T-10) with the compromised and invalided W_{tube} with the Ar gas pressure at 900 Pa (= 7 Torr). The CCFL tubes for the color neon sign had made with the outer diameter 1.5×10^{-2} m with monochrome PL phosphor screens. The adequate phosphor screens for the neon-sign tubes had selected by the try and error approaches [6. 7].

As the depths of the gap are shallower than 1×10^{-3} m, the temperature of the phosphor screen is determined by the cool air convection on the outer glass wall. There is a way for the protection of the cooling by the air convection at the outer glass wall. The plural coil-EEFL tubes in the high Ar gas pressures set in the vacuum-sealed glass tube with the vacuum pressures less than 2×10^3 Pa (< 15 Torr). The cooling of the phosphor screen of the coil-EEFL tubes by the cool air convection is prevented, resulting in the rapid build-up curve of the illuminance (lm m^{-2}) with the same coil-EEFL tubes. The saturated illuminance (lm m^{-2}) of the FL tubes in the sheath tube also goes up.

Following experiments are preliminary experiment. The diameter of the positive column of the commercial 40W-HCFL tubes (T-10) is 2.2×10^{-2} m $\{= (3.0 - 0.4 \times 2) \times 10^{-2}$ m$\}$. The diameter of the positive column of the coil-EEFL tube (T-3) is 8×10^{-3} m $\{= (0.9 - 0.04 \times 2) \times 10^{-2}$ m$\}$. If the coil-EEFL tubes (T-3) set in the vacuum-sealed glass tube in the outer diameter 3.2×10^{-2} m (T-10), total positive column of the 3 coil-EEFL tubes is 2.4×10^{-2} m that is equivalent with the commercial 40W-HCFL tube. By the preliminary experiments, the 3 coil-EEFL tubes having Ar gas pressure at 9×10^3 Pa (= 50 Torr) set in vacuum-sealed glass tube in the outer diameter of 3.2×10^{-2} m (T-10). As the 3 coil-EEFL tubes in the opaque sheath tube are operated with the external DC driving circuit at 4 kV, the opaque sheath tube may emit the more than 6 times of the illuminance of the nominal 40W-HCFL tube with the $W_{DC} = 0$. The W_{act} of the nominal 40W-HCFL tube is 80 watt with the ballast and 60 watt with the inverter. Unfortunately, I could not continue the experiments with the serious sick. I moved to China for the cure of the sick. I cannot find the adequate facilities of the coil-EEFL tubes in China. The further confirmation of the exciting feature of the coil-EEFL tubes in the opaque sheath tube remains for a future study by someone else.

4-b-ii) Arrangement of CL and PL phosphor particles side by side on top layer of phosphor screen

Historically, the phosphor screens for the FL tubes have considered as the transducer of the UV lights to the visible lights. The optimized phosphor screens as the transducer of the UV lights determined the PL phosphor screens before 1970 [6, 7, 19]. The selected PL phosphor screens emit the dark CL in CRT. The brighter CL phosphor screens dim in the FL tubes. The reasons have stayed as the mystery.

We have the studied the PL and low-voltage CL phosphor screens in the FL devices. We have the interesting results [20]. As the phosphor screen is made with the PL phosphor particles, the surfaces of the PL phosphor particles in a vacuum are covered with the surface bound electrons (SBE) [18]. The electrons move on in the volume of the Ar gas space defined by $F_{vect} \geq F_{SBE}$, as illustrated in Figure 30. As the phosphor screen in the FL tube is made with the low voltage CL phosphor particles, the surface of the CL phosphor screen does not have the electric charge, so that the $F_{phos} \approx 0$. The electrons selectively move on in the surface conduction of the phosphor screen under the F_{vect} [12]. The surface conductive electrons have the small probability to meet the Ar atom, resulting in the dim PL in the FL tubes.

After the experimental results, we have an interesting idea for the phosphor screen in the FL tube [20]. We have spread the small amount of the low voltage CL phosphor particles on the PL phosphor screen. The new phosphor screen emits the brilliant PL in the FL tubes. As the electrons from the cathode move on the surface conduction of the low voltage CL phosphor particle, the surface area of the CL phosphor particle is 2.5×10^{-11} m^2 (= 5×10^{-6} m$)^2$ that is the wide enough area for the moving electron in the diameter of 5.6×10^{-15} m. The electrons on the surface of the CL phosphor particles are accelerated by the F_{vect}. The accelerated electrons on the surface of the CL particles receive the strong Coulomb's repulsion from the SBE on the neighbor PL phosphor particles. The repulsed electrons are the strongly scattered electrons to the positive column. But many electrons in the positive column again reach on the surface of the CL phosphor particles. The electrons are accelerated by the F_{vect}. The accelerated electrons on the CL phosphor particles receive the strong Coulomb's repulsion from the neighbor PL phosphor particles. The moving electrons in the FL tube continuously duplicate the reaching on the CL phosphor particles and scattering from the PL phosphor particles. The discontinuity of the surface conduction on the CL phosphor particles is 5×10^{-6} m that is beyond the resolution of the naked eyes. The depth of the gap with the phosphor screen is apparently zero depth. Hence we have the new structure of the phosphor screen for the advanced FL tubes in the diameters narrower than 1×10^{-2} m.

We have found that the red Y_2O_3:Eu red phosphor particles have the threshold voltage at 110 volts so far as the surface of the particles have the clean surface physically and chemically. We have spread the red Y_2O_3:Eu red phosphor particles on the green and blue rear-earth phosphor screen in 3 layers. The phosphor screens in the FL tubes have the negligible gap in the lighted FL tubes. Hence, we have found the new structure of the phosphor screen for the shallow depth of the gap in the FL tubes.

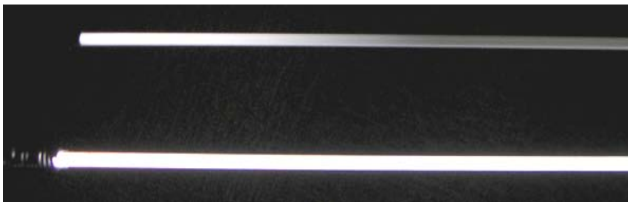


Figure 32 : Photograph of lighted coil-EEFL tubes; with commercial phosphor screen (above) and the improved phosphor screen (below)

The next subject is how do make the blend mixture of the low voltage CL phosphor powder and PL phosphor particles. We have selected the average particle size of the Y_2O_3:Eu red phosphor particles is 0.5 x 10^{-6} m small as compared with the particles of the green and blue rear-earth phosphor particles. The blend mixture of the phosphor powder is made with the about 30 wt % of the red phosphor powder. Figure 32 shows photopicture of the lighted coil-EEFL tubes; the commercial phosphor screen (above) and improved phosphor screen (bottom). The both tubes are operated with the parallel connection under the single DC electric power at 2 kV. As the coil-EEFL tubes have the improved phosphor screen, the entire length of the phosphor screen uniformly emits with the W_{DC} = 0. On the other hand, the light intensities of the regular phosphor screen decreases with the distance from the cathode. We have developed the new phosphor screen for the coil-EEFL tubes. The results are applicable to the ordinal FL tubes.

V. Production Facilities for Advanced Coil-EEFL Tube

This is not the scientific study. This is the technical skills. The major commercial HCFL tubes in the outer diameter of 3.2 x 10^{-2} m (T-10) as the major incandescent lamps are produced with the automated production lines for more than 60 years. It has believed that the automated production lines of the HCFL tubes have well optimized with the production technologies of the HCFL tubes. However, the established production lines cannot produce the advanced coil-EEFL tubes with the acceptable illuminance (lm m^{-2}); especially the diameters less than 1.3 x 10^{-2} m. This is because that the HCFL tubes that are produced by the established production lines contain the large amount of the residual gases of air (mixture of N_2 and O_2), water, CO_2 and decomposed oil vapors of the pumping oil. All of them are invisible by the naked eyes.

We had the drilled study on the darkening of the phosphor screen of the monitor CRTs for computer as far as the CRTs contained the residual gases at around 0.1 Pa (10^{-3} Torr). The phosphor particles in the screens in CRTs were periodically polarized under the irradiation of the electron beam. The periodically polarized phosphor particles in the residual gases have the catalytic action to form the methane gas CH_4 by the selection of the CO_2 and H_2O gases among the residual gases. Then the methane gas is polymerized to the hydrocarbons, C_nH_{2n+2}, on the periodical polarized phosphor particles. The surface of phosphor particles is covered with the layer of the polymerized hydrocarbons; resulting in the darkening with the operation time. The darkness of the phosphor screen of the monitor CRT significantly reduced to the acceptable level by the reduction of the residual gas in the vacuum-sealed CRTs.

The phosphor particles under the EEs of the coil-EEFL tube are periodically polarized under the AC external driving circuit. We have converted the commercial 40W-HCFL tubes to the coil-EEFL tubes with 3 turns of the EEs; one is a new HCFL tube and another is life terminated HCFL tube. The converted coil-EEFL tubes are operated with the AC driving circuit of 4 kV_{rms} with 30 kHz for three days. Then, the positions of the EEs shift to the end sides. Figure 33 shows the results. You may see three dark lines of the lighted EEFL tubes for the operation of three days. The dark lines are caused by the polymerized hydrocarbons, like as the CRTs. The above coil-EEFL tube in Figure 33 is the life-terminated HCFL tube. By the conversion to the coil-EEFL tube, the FL tube lights up, but the entire phosphor screen emits slightly dark by the covering of the thin layer of the hydrocarbons. The life-terminated HCFL tube contains the large amount of the polymerized hydrocarbons, so that the coil-EEFL tube gives three dark lines. The bottom photograph is the coil-EEFL tube converted from the new HCFL tube. We may see the three lines but the darkness is a low level. The photograph in Figure 33 definitely shows the presence of the polymerized hydrocarbons from the residual gases in the commercial HCFL tubes. The amount of the polymerized hydrocarbons gradually increases with the operation time.

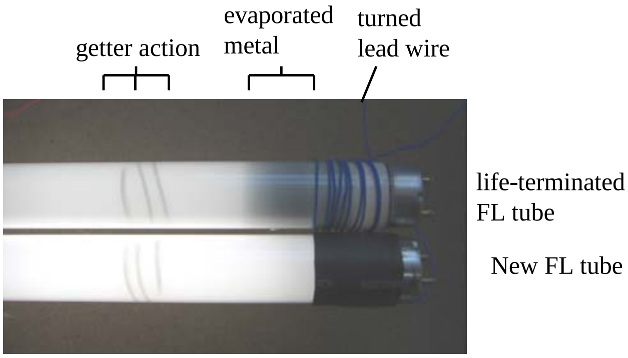


Figure 33 : Photograph that indicates getter action of periodically polarized phosphor particles under EEs that are operated with external AC driving circuit of 3 kV_{rms} and 30 kHz

Notwithstanding the HCFL tubes have experienced the degassing process during the pumping process to the vacuum less than 10^{-3} Pa (< 10^{-5} Torr) that determines on the control panel, the commercial HCFL tubes are heavily contaminated with the residual gases at the pressures at around 500 Pa (a few Torr). The strong sky-blue light from the Ar* in the produced FL tubes conceals the large amount of the residual gases. You may simply detect the amount of the residual gases in the produced FL tubes with the following way. The vacuum sealed glass tubes without the electrodes, phosphor screen, Ar gas, and Hg droplets are produced with your production facilities. In this case, you may certainly identify the residual gases by your naked eyes.

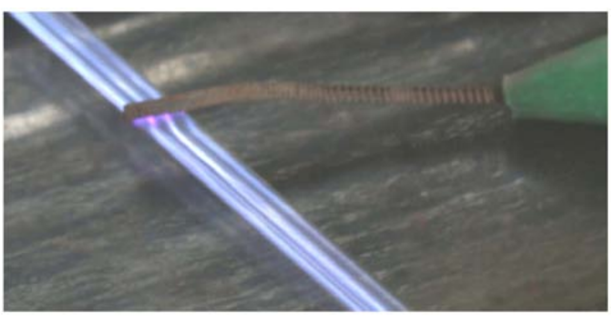


Figure 34 : Photograph of lighted vacuum-sealed glass tube under Tesla coil. Tubes are immediately after vacuum seal from pumping facility

The largest residual gases come from the vacuum-sealing process of the pumping glass tube (tip-glass tube). You may detect the vacuum pressure of the glass tubes on the pumping facilities with the Teslar coil. You may surely detect no light that is the vacuum pressure less than 10^{-3} Pa (=10^{-5} Torr). The glass tubes separate from the pumping facilities by the melting down of the tip-glass tube. The melted glass tube releases a large amount of the gases from the melted glass. Some amount of the released gases inversely diffuses in to the vacuum of the glass tube. The melted tip glass instantly closes the tip-glass tube before the pumping out of the inversely diffused gases in the glass tubes. Consequently, the pumped FL glass tube traps some amount of the released gases in the vacuum-sealed glass tubes. The trapped gases in the glass tubes can be detected by the colors of the lights under the Tesla coil. Figure 34 shows, as an example, photograph of the contaminated gases in the vacuum-sealed glass tubes immediately after the pumping process. The kinds of the residual gases can be identified from the color of the lighted glass tubes. The major gases are water (H_2O), CO_2, N_2 and O_2 gases. The amount of the trapped residual gases has estimated from the light intensity. It is around 500 Pa (a few Torr). After one-overnight, the vacuum-sealed glass tubes do not emit the light under the Tesla coil. The cavities on the surface volume of the inner wall of the glass tubes adsorb all residual gases. The cavities in the surface volume of the glass tube release the some of the residual gases under the Teslar coil for a while. The other residual gases in the cavities charge up in the operation of the FL tubes. You must find out how do close the pumped glass tubes without the discharge of the large amount of the residual gases. This can be done by the heating the tip glass tube at the softening temperature. The softened glass releases the negligible amount of the gases. This is very important information for the production of the reliable coil-EEFL tubes.

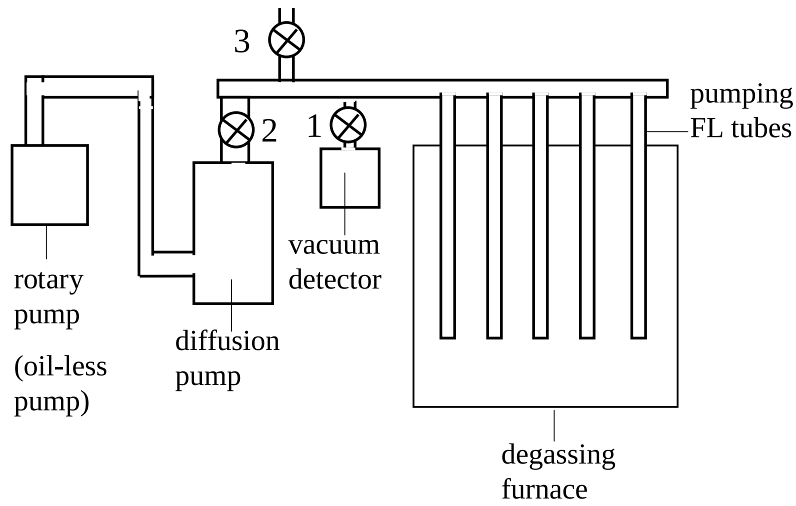


Figure 35 : Inadequate pumping system of production of coil-EEFL tube

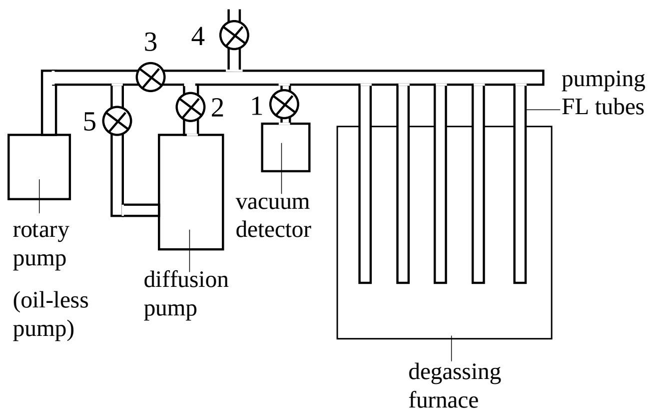


Figure 36 : Schematic illustration of proper pumping facilities using oil-less rotary pump

Next serious problem is the contamination of the decomposed oil vapors of the vacuum pumps, especially Asian countries. We have experienced in Japan, Korean, Taiwan, China, and others. They use the very expensive and advanced pumping facilities for the production of the FL tubes. Here is a problem. The air in the FL tubes directly pumps out through the diffusion pumps as illustrated in Figure 35. Even though the pump producers claim the safety of the oil with the pumping air, the pumping oils are contaminated with the air in the working rooms. The contamination of the decomposed oil vapors are well studied in the growth of the pure single crystals and thin films of the semiconductors. In general, the air in the room is heavily contaminated with (a) the invisible fine solid particles, (b) chemical gases, and invisible water drops as the moisture. Although the air in the working rooms controls the humidity below 30 %, the water drops in the working room certainly contain the insoluble tiny particles. You may confirm it. You set the thin glass plate in the working room. The back side of the glass plate slowly cools down to the temperature at 0°C. The glass plate on front side is slowly covered with the condensed water drops in the small size. As the small water drops on the glass plate observe under the optical microscope (x higher than 100 times), you may detect tiny particles in the water drop. The tiny particles are the core for the formation of the water drop (moisture) in the air. The tiny particles are various color and sizes, depending on the contaminated air in the room. If you have arranged the diffusion pump shown in Figure 35, the pumping oil is slowly but surely accumulates the contaminated particles and gases with the operation days. The contaminants slowly react with the heated pumping oil. The decomposed oils have the high vapor pressures that have the inverse diffusion from the pumping system. The inside surface of the phosphor screen in the produced FL tubes is heavily contaminated with the thin atomic layers of the inverse-diffusion of the decomposed oil vapor. The FL tube is also contaminated with the decomposed oil-vapors of the rotary pump.

The commercial HCFL tubes may accept the contamination of the pumping oil with the deep gap (4 x 10^{-3} m) between positive column and phosphor screen. However, the coil-EEFL tubes should have the gap shallower than 3 x 10^{-4} m. The coil-EEFL tubes do not allow the contamination of the inverse diffusion of the decomposed oil vapor. We have experience the similar problem with the development of the very high resolution of the miniature CRT (1 x 10^{-4} m^2) on 1993 [21]. The surface of the phosphor particles is covered with the contaminated oil vapor in atomic layer that charges up in the vacuum. You never produce the acceptable coil-EEFL tubes in the diameter less than 1 x 10^{-2} m with the pumping facility shown in Figure 35.

For the study of the coil-EEFL tubes, you step in the most advanced vacuum technology, not the expensive pumping facilities. You should use the simple vacuum facilities shown in Figure 36 for the protection of the contaminants in the working room and the decomposed oil vapor of the vacuum pumps. The diffusion pump only operated with the vacuum pressure below 10^{-1} Pa (< 10^{-3} Torr). The diffusion pump never pumps out the air in the rooms. You never use the oil-rotary pump. You must use the oil-less rotary pump for the production of the reliable coil-EEFL tubes.

Next problems are the heating furnaces of the production of the FL tubes. We will describe the degassing of the trapped gases in the surface volume of the glass tubes and phosphor particles. The degassing temperature at 350°C is high enough for the degassing from the trapped gases in the vacancies in the surface volume of the glass tube and phosphor particles. The small amount of the gases releases with the heating temperatures above 350°C. These gases are uniformly trapped in the entire glass tube and phosphor particles. The degassing process is for the release of the trapped gases in the cavities of the surface volume of the phosphor particles and glass tubes.

You should care the glass tube is the good thermal insulator. You must equally heat up the entire glass tube to the 350°C at the degassing furnace. Here is the problem in Asian countries. In the production of the FL tubes and CRTs, the heating temperature of the furnace is controlled with the temperatures on the control panel. There is a large temperature differences between the temperature of the heated glass tube and the temperature of the control panel. Furthermore, the heaters of the furnace are not covered with the heat-scattering plates. The glass tubes in the furnace are heated by the thermal radiation from the heaters in the furnace. The heaters in the furnace must be covered with heat scattering panel. This is the common sense of the design of the furnace. They do not have the common sense to design of the furnace. Accordingly, the temperature profile of the furnace is poor as illustrated in Figure 37 at the bottom. Furthermore, the thermocouple sets in the improper position in the furnace.

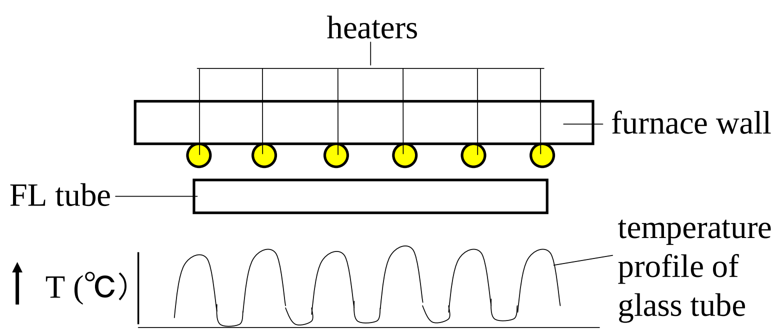


Figure 37 : Arrangement of heaters in degassing furnace of pumping facility

They well control the temperature on the control panel that does not correspond to the temperature of the glass tubes. The cavities in the surface volume of the phosphor particles and glass tube contain large amount of the adsorbed gases. The fact of the no degassing process can simply examined by the high Ar gas pressure. The heat source of the FL tube is solely ionization of the Ar atoms. If the FL glass tubes contain the Ar gas pressure higher than 3 x 10^3 Pa (20 Torr) without Hg vapor, the FL tubes without phosphor screen emit the sky-blue for a moment. Then the inner glass wall instantly heat up to the temperature above 80°C. The cavities in the surface volume instantly release the trapped gases with the whitish light and red color lights. If the entire glass tubes are completely degassed at 350°C in the pumping furnace, the glass tubes with the Ar gas emit the pure sky-blue lights even with the Ar gas pressure at 10^4 Pa (=100 Torr).

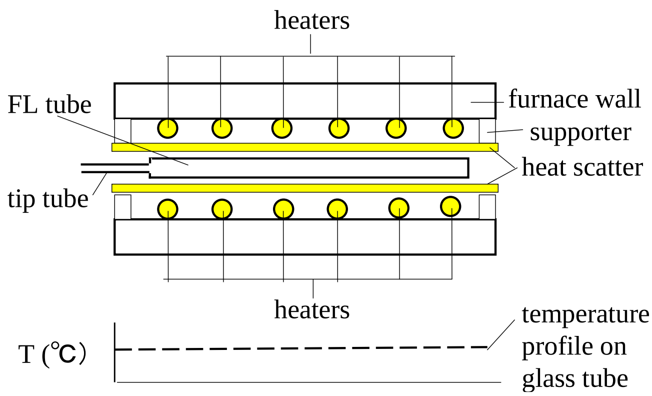


Figure 38 : Appropriate degassing furnace that heaters are covered with heat scatter panel between heaters and heating room. Bottom shows temperature profile on surface of glass tube

Figure 38 illustrates the ideal furnace of the degassing and baking of the phosphor screen of the FL tubes. The heaters are covered with the thin heat scatter plates, like as the SiO_2, Al_2O_3, and other refractories. The bottom curve shows the temperature profile on the surface of the FL glass tubes. The temperature detector (thermocouple) should set at the 1 x 10^{-2} m above or below FL tubes. The entire area of the FL tubes uniformly heats up to the given temperatures. The heating conditions are not the temperatures on the outer surface of the FL tubes. The inner wall of the glass tube and the surface volume of the phosphor screen on the inner wall should be heated at 350°C for at least 30 minutes for completely degassing from the cavities in the surface volume. You do not use the expense borosilicate glass tube for the production of the FL tubes. You can use the ordinary sodium lime glass tube for the production of the coil-EEFL tubes.

The surfaces of the commercial FL phosphor particles deliberately and heavily contaminated with the layers of the by-products in the production process and the deliberately added microcrusters on the surface of the phosphor particles as shown in Figure 28. With this reason, we never use the commercial phosphor powders for the experiments of the acceptable coil-EEFL tubes. The details of the preparation of the advanced phosphor powders refer the published books [18]. The PL and CL phosphor particles for the coil-EEFL tubes should have the clean surface chemically and physically as well as the sharp edge lines and sharp points. The best phosphor powders are produced with the heating programs of the blend mixtures of the raw materials. The expensive facilities do not produce the acceptable products. The acceptable products are produced with the excellent maintenance of the production facilities. This is the important consideration for the study of the advanced coil-EEFL tubes.

VI. Conclusions

After the careful study on the fundamentals of the established FL tubes, we have found that the commercial FL tubes are produced with the premature technologies. Then, we have studied the new lighting mechanisms of the FL tube that leads us to the development of the coil-EEFL tube. The coil-EEFL tubes form the internal DC electric power generator in the Ar gas space under the electric field of the external driving circuit. There is no electron flow between the disparities of the electric circuits. The lights are solely generated with the moving electrons between cathode and anode of the isolated internal DC electric power generator formed in the Ar gas space. The electrons move on in the superconductive vacuum between Ar atoms, giving rise to the astronomical quantum efficiency, $\eta_q = 10^{13}$ visible photons $(m^3, s)^{-1}$ with no power consumption of the external DC driving circuit; $W_{DC} = 0$. Furthermore, there is no consumption of the components in the operation to the coil-EEFL tube, prolonging the operation life longer than 10^6 hours.

For the production of the advanced coil-EEFL tubes, we cannot use the existing production facilities and commercial phosphor powders for the coil-EEFL tubes. The main reasons are below: (i) The pumping oils of the established FL productions are heavily contaminated with the polluted materials in the air of the working room. (ii) The FL glass tubes are a good thermal insulator; the existing furnaces for the FL production have the inadequate temperature profiles for uniform heat of the entire FL glass tubes. And (iii) the trajectory moving electrons in the Ar gas space are severely influenced with the improper distribution of the electric charges on the phosphor screens by the commercial phosphor powders.

The developed coil-EEFL tubes that brilliantly light up with the $\eta_q = 10^{13}$ photons (m3, s)$^{-1}$under the zero electric power consumption of the DC driving circuit. The coil-EEFL tubes are the unrivaled incandescent lamp over the LED lamps that have only η_q < 0.8 maximum. The developed coil-EEFL tubes are the suitable incandescent light sources for the illumination of the rooms. The coil-EEFL tubes may also use the backlights of the LCD panel for the computer display and TV sets with the zero of the electric power consumption and long operation life. The developed coil-EEFL tubes may contribute to the green energy project (COP; Conference of the Particles) on the world.

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