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ELECTRIC CHARGES ON PHOSPHOR PARTICLES DETERMINE FEATURES OF LIGHTED FL TUBES

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ABSTRACT

The lighting devices such as coil-EEFL tube, HCFL tube, PDP and flat fluorescent lamp (FFL) use the opaque phosphor screen as the transducer from the UV lights to the visible lights. The phosphor screens as the transducer of the UV lights have already optimized. The lighting mechanisms in the inside of the FL tube are invisible by the naked eyes. The lights in the lighting devices originate from the excitation of the floating Hg atoms by the moving electrons in the positive column which is defined as the $V_{vect} \geq F_{phos}$ in the Ar gas space. The F_{phos} on the phosphor screen in the FL tubes ever report in the past. The surfaces of the phosphor particles in the screens are deliberately contaminated by the impurities of the electric insulators. The impurities on the phosphor particles in the lighted FL tubes form the surface bound electrons (SBE), giving rise to the depth of the gap of 4×10^{-3} m (= 4 mm), independent on the diameters of the FL tubes. The deep gap severely restricts the illuminance of the lighted FL tubes. The lighted low voltage CL phosphor particles do not have the SBE, but the electrons selectively move on the surface conduction on the phosphor screen in the FL tubes. We have obtained the fundamental data of the formation mechanisms by the $V_{vect} \geq F_{phos}$ and of the reduction of the depths of the gap to 1×10^{-4} m. The optimal arrangements of the phosphor particles in the phosphor screen of the coil-EEFL tubes are underway.

KEYWORDS: FL tubes, PDP, FFP, phosphor screen, positive column,.

INTRODUCTION

Our life activities move to the offices in the large buildings in daytime and to the rooms of houses in night. The daily activity necessitates the illuminated offices and rooms by the lighting devices. After the discovery of the electrons, the light sources have shifted from the candescent lamps to the incandescent lamps. The word of "candescent" comes from ancient Greek that means the flame of the fire. The candescent lamps use the flame of the fire by the chemical reaction with the oxygen in air. The incandescent lamps light up by the use of the moving electrons in solids and inert gases. The incandescent lamps use the electric power from the electric power generators. It is said that the electric power consumption, W_{act}, by the illumination is around 25 % of the total electric energy generated by the electric power stations on the world. The power consumption of the illumination will increase every year by the involvement of the developing countries. The reduction of the electric power consumptions by the lighting sources becomes a serious concern for the protection of the antipollution by CO_2 from the electric power generators on the world.

The major established light sources in our life activity at the present time are the FL tubes, and heated tungsten filament lamps. The tungsten filament lamps use the heated tungsten filament by the Joule Heat (I^2R). The lights from the FL tubes do not use the Joule Heat. The FL tubes use the combination of (a) the UV lights from the excited Hg atoms in the vacuum and (b) the phosphor screen as the transducer from the UV lights to the visible lights. Recently, the LED lamps emerge as the energy saving light source [1]. The LED lamps are solid lighting source. The LED lamp emits a visible photon as the consequence of the recombination of the pair of the injected electron and hole at the luminescence center. However, we do not have the scientific proof of the claims of the LED lamp as the energy savor. The LEDs are a kind of the phosphor particles. The operation voltage of individual LED lamp is DC 2.8 V, but the LED lamp is operated with a huge amount of the DC electric current, due to the number of the emitted photons directly relates with the number of the injected electrons to the LED. The generation of the lights of the both FL tube and LED use the moving electrons. The large difference between them is the moving conditions of the electrons. LED uses the moving electrons in the solid and FL tube uses the moving electrons in vacuum. A figure of the merit of the lighting devices by the moving electrons is the quantum efficiency η_q [2]. The η_q is given by the ratio of the number of the generated photons in the visible wavelengths by one injected electron into the light device. At first, we may study the η_q of the emerging LED lamp.

The LED lamps are made with the crystallized solids. The LED lamps generate a visible photon (light) by the recombination of a pair of the injected electrons and holes at the luminescence center in the crystallized solid. The solids are not superconductor. The LED solids have the electric resistance (R) that is caused by the thermal perturbation from the thermal vibration of the neighboring atoms (~ 10^{-10} m separation) at the lattice sites in the solid. The injected electrons and holes to the LED lamp inevitably receive the thermal perturbation from the neighboring atoms at the lattice sites, giving rise to the electric resistance, R. The injected electron into the LED loses the some energy by the Joule Heat that is given by I^2R, where I is the electric current (i. g., number of the flowing electrons per second). The commercial LED lamps have the $\eta_q \approx 0.5$ [1]. If the LED crystal is made by the superconductive crystal, the $\eta_q = 1.0$, but it is impossible with the reason that the solid of the LED lamp is not the superconductive solid. In the future, the LED may be produced by the improved solids that may give the $\eta_q = 0.8$. We take here $\eta_q = 0.8$ for the following calculations for the future LED lamps. As the practical light source, the LED lamp on the unit dais (e.g., 1 x 10^{-4} m^2 = 1 cm^2) should emit 10^{25} photons per second for the illumination of 1 m^2 room [3]. The number of the injected electrons to the LED lamp is 10^{25} electrons per second; corresponding to the 1.2 x 10^6 A {= 10^{25} x (10^{-19}) x 0.8^{-1}}. 1 A is 1 Coulomb per second. The electric current by the loss of the Joule Heat is 2 x 10^5 A (= 10^6 x 0.2 A). As already mentioned, the Joule Heat is given by I^2R. Even though R in the very thin of the LED film in 10^{-6} m is around 0.3 Ω per 1 x 10^{-4} m^{-2} dais, the Joule Heat from the LED lamps is 1.2 x 10^{10} W {= (2 x $10^5)^2$ A x 0.3 Ω}. The electric resistance is caused by the thermal perturbation from the thermally vibrating atoms at the lattice sites. The separation distance by the lattice sites is the order of 10^{-10} m. The thermal perturbed of the LED can be proved by the measurement of the absorption spectrum of the LED film by a spectrometer. You will certainly detect the absorption bands. The electrons of the LED move on in the wide conduction band that generates the Joule Heat. The LED consumes the large amount of the electric energy in the operation as the heat. We cannot expect the save of the electric energy by the use of the LED lamps as the illumination source.

On the other hand, the Ar atoms in the FL tubes float in the vacuum with the Maxwell-Boltzmann distribution. The separation distance between Ar atoms is 2 x 10^{-7} m that is large enough space of the moving electron in the diameter of 5.6 x 10^{-15} m. Each floating Ar atom thermally vibrates at given floating position in the vacuum. The distance of the thermal vibration of the Ar atoms is restricted to the vacuum space less than 10^{-9} m. The moving electrons in the vacuum between Ar atoms in the FL tube are not disturbed by the thermal perturbation from the neighboring Ar atoms. The absorption spectrum of the Ar gas space in FL tube consists of the lines, indicating that the energy levels of the Ar gas atom do not receive the thermal perturbation from the neighboring Ar atoms. The vacuum space between Ar atoms provides the superconductive vacuum for the moving electrons [2].

Each moving electron in the superconductive vacuum in the lighted FL tubes moves from the cathode to the anode of the internal DC electric power generator in the Ar gas space [4]. The moving electrons from the cathode to the anode scatter with the Ar atoms that float in the vacuum. The scattering with the Ar atoms results in the ionization and excitation of the Ar atoms but the moving electrons never disappear from the vacuum in the positive column. We may statistically calculate the number of the excited Ar atoms in the FL tubes. As the statistical consideration, the mass of the Ar^{1+} and Ar* is ~ 1.6 x 10^{-27} kg and mass of electron is 9.1 x 10^{-31} kg. Under the same vector electric field, F_{vect}, the electrons move faster of 10^4 times as compared with the moving speed of the ions and excited atoms. In the discussion of the operation of the FL tubes, we may only consider the electrons as the moving particles, and Ar^{1+} and Ar* stay at the same vacuum position. The calculated number of the Ar atoms in the positive column of the practical FL tubes is 10^{16} Ar atoms (m^3, s)$^{-1}$.

The origin of the light source in the FL tubes is not the excited Ar*. The lights source in the FL tubes assigns the UV lights from the excited Hg atoms in the Ar gas space. The evaporated Hg atoms in the Ar gas space are the 10^{-3} times of the Ar atoms [3]. Statistically, the number of the excited Hg atoms by one moving electron is 10^{13} Hg atoms (m^3, s)$^{-1}$. Each excited Hg atom emits one photon of the 254 nm UV light. The phosphor screen transduces the UV lights to the lights in the visible spectral wavelengths with the $\eta_q \approx 1.0$. Consequently, the positive column of the lighted FL tubes has the astronomical quantum efficiency $\eta_q = 10^{13}$ visible photons per unit volume of the Ar gas per second, (m^3, s)$^{-1}$.

We must confirm the calculated results by the practical evidence. The astronomical $\eta_q = 10^{13}$ photons $(m^3, s)^{-1}$ is proved by the number of the emitted photons from the positive column of the commercial 40W-HCFL tube. The moving electrons in the internal DC electric circuit in the positive column of the commercial 40W-HCFL tube are 0.2 mA maximum that corresponds to 10^{15} electrons per second. The electrons only move on in the volume of the positive column. The volume of the positive column in the commercial 40W-HCFL tube in 1.0 m long is calculated as 0.03 m^3. The commercial 40W-HCFL tube emits the 3 x 10^{25} photons per second (= 10^{13} x 10^{15} x 0.03 m^3) [2] without the Joule Heat. One commercial 40W-HCFL tube may illuminate the room in 3 m^{-2} with the daytime scenery under the slightly overcastting sky that the human eyes adjust for 5 million years. The calculation from the number of the emitted photons from the commercial 40W-HCFL tube is verified by the practice.

However, the unrivaled advantages of the FL tubes have concealed in the study on the FL tubes for 80 years by the evaluation with (a) the invalidated luminous efficiency (lm W^{-1}), (b) the hypotheses of the direct injection of the thermoelectrons into the Ar gas space, (c) determination of the AC power consumption with W (= W_{tube}), instead of the W_{act}, and (d) the misinterpretation of the waveform detected at the electrodes of the FL tube [3]. The luminous efficiency is for the study on the colorimetry. The light sources are evaluated with either (i) luminance (cd m^{-2}), or (ii) illuminance (lm m^{-2}), (iii) irradiance (W_{photon} m^{-2}), and (iv) number of the visible photons per m^{-2} [3]. The comfortable illumination level of a given room is given by the illuminance of 330 lm m^{-2}, that corresponds to the daytime scenery under the slightly overcastting sky.

The studies on FL tubes have a long history since the invention on 1928 [5]. After the inventions, there are many reports on the FL tubes [6, 7, 8, 9]. The FL tubes have studied for the long time and the annual production volume of the FL tubes are the multimillions on the world. The scientists, engineers, and investors have believed the mature technology of the FL tubes. According to the conclusion, the systematic study on the FL tubes had terminated in USA on 1970s. As far as the study of the FL tubes makes with the established publications mentioned above, one may get the same conclusion.

Recently, we have studied the FL tubes with the different views from the established publications. We have found that the performances of the established FL tubes have made with the invalided hypotheses and misunderstanding to the experimental results. After the removal of the invalided items, we have revealed that the FL tubes may have the unrivaled advantages as the light sources over the solid lighting sources [10]. The advantages of the lighted FL tubes, which we have revealed, are:

[1] Coexistence of the disparities of the external AC driving circuit and internal DC electric circuit in the operation of the lighted FL tubes as unit [11]. The external AC driving circuit is visible by the naked eye that is the figurative matter. The internal DC electric circuit is invisible by the naked eye because the opaque phosphor screen covers up the inside of the FL tubes. The internal DC electric circuit belongs to the abstraction by the thinking in the brain. The modern science is developed by the proofs of the abstraction with the scientific evidences. The disparities of the electric circuits have the totally different functions in the operation of the lighted FL tubes.

[2] The external AC driving circuit never injects the electrons into the Ar gas space [4, 11,]. The established concept had made by the assumption that the cathode electrodes of the FL tube directly inject the electrons into the Ar gas space and the anode electrode collect the electrons from the Ar gas space. In reality, the external AC driving circuit is electrically closed with “the induced AC current” at the electrodes of the lighted FL tube. The induced AC current is not by electron flow. The electrodes of the FL tubes pick up the induced AC current from the synchronous displacement of the distribution of the electrons in the Ar^{1+} that forms the capacitor C_{tube} [11]. The electrodes of the FL tube do not closed by the flowing electrons in the Ar gas space. The AC induced current apparently close at the electrodes of the FL tubes. Subsequently, the electric power consumption, W_{act}, of the external AC driving circuit does not relate to the generation energy of the lights in the lighted FL tubes. It follows that the evaluation by the luminous efficiency (lm W^{-1}) invalids in the study on the FL tube [3].

[3] The electron sources in the commercial HCFL tubes are the new electron sources by the volume of the heated and ionized Ar atoms that is the 4G generation electron source in the FL tubes [12]. The 4G electron sources are called as the high temperature Ar corona space, HTACS.

[4] The unnecessary W_{act} of the current HCFL tubes for the generation of the lights can be reduced to 0.03 W_{act} by the application of the coil-EEFL tubes, holding the same illuminance (lm m^{-2}) [13]. The power consumption of the internal DC electric circuit is less than 0.01W, but is isolated from the W_{act} of the external

AC driving circuit.

[5] The electric power consumption of the operation of the coil-EEFL tubes will be zero with the holding the same illuminance, if the coil-EEFL tubes are operated with the external DC driving circuit [4].

According to the new findings, we must find out the restrict factors of the moving electrons in the Ar gas space in the internal DC electric circuit. The internal DC electric power generator and the moving electrons in the Ar gas space are invisible by the naked eyes. The moving electrons in the Ar gas space exclusively generate the lights in the lighted FL tubes. Each moving electron has the negative charge of 1.6 x 10^{-19} Coulomb. Therefore, the moving electrons between cathode and anode of the internal DC power generator are sensitively influenced by the localized scalar electric fields, F_{scal}. There is no considerable magnetic field from the moving electrons in the lighted FL tubes. In general, we neglect the magnetic field in the F_{scal}. The F_{scal} in the lighted FL tubes are (a) the localized electric field from the electrons in the orbital electrons of the Ar atoms, F_{orb}, and (b) the vertical electric field from the electrons on the phosphor screen, F_{phos}. The F_{orb} scatters the moving electrons from the longitudinal vector electric field, F_{vect}, between the cathode and anode. The scattered electrons by the F_{orb} stay in the positive column. Statistically, the electrons move from the cathode to the anode. The staying of the scattered electrons by the F_{orb} in the positive column determines the astronomical quantum efficiency η_q [2].

The story of the F_{phos} differs from the F_{orb}. The diameter of the positive column in the Ar gas space is determined by the F_{phos}. The F_{phos} has the electric field to the vertical direction against the longitudinal F_{vect}. The F_{phos} from the phosphor screen pushes back the approaching electrons to the volume of the Ar gas in the positive column, which is defined by the $F_{vect} \geq F_{phos}$. The moving electrons never involve in the electric conductance of the phosphor screen. Consequently, there is the gap between phosphor screen and positive column. The moving electrons in the positive column cannot step in the gap which $F_{vect} \leq F_{phos}$. The moving electrons stay in the volume of the positive column and excite the evaporated Hg atoms in the positive column [14]. The UV lights in the lighted FL tubes solely generated in the positive column by the excitation of the Hg atoms in the Ar gas space in the positive column.

The Hg atoms in the positive column come from the evaporation of the Hg droplets on the phosphor screen. Here is a problem that the positive column is surrounded with the Ar gas in the gap. The Ar gas is the good thermal insulator that restricts the evaporation of the Hg atoms from the Hg droplets on the phosphor screen. The Ar atoms in the gap at the Ar gas pressure 1 x 10^3 Pa (≈ 7 Torr) are a good thermal insulator with 4 x 10^{-7} cal $(m, s, deg)^{-1}$. The positive column is surrounded with the thermal insulator. The Hg atoms must evaporate from the Hg droplets on the heated phosphor screen by the heat radiation from the positive column. The heat source in the lighted FL tubes is only ionization of the Ar atoms in the positive column by the change in the entropy. The heating speed of the Hg droplets on the phosphor screen is a slow with the deep gap that fills up with the thermal insulator.

Furthermore, the Ar gas in the gap contains the large amount of the unexcited Hg atoms that absorb the UV lights from the positive column before reaching to the phosphor screen [14]. The phosphor screens transduce the UV lights on the phosphor screen to the visible lights with the $\eta_q \approx 1.0$, corresponding to one visible photon by one UV photon. The illuminance of the given FL tubes seriously changes with the depths of the gap in the lighted FL tubes [14]. For the increase in the illuminance from the produced FL tubes, the depth of the gap should minimize as possible. For the reduction of the depths of the gap, the residual gases in the produced FL tubes mainly come from the sealing process of the vacuum of the pumping glass tube, independent of the degassing process of the FL tubes and pumping facilities [14].

Before the considerations described above, there are the serious problems in the present pumping facilities. The pumping facilities of the FL producers in the Asian countries, including the research laboratories, do not have the periodical maintenance of the pumping facilities. The inside-walls of the pumping facilities are heavily contaminated with the decomposed pumping oil. Furthermore, the pumping oils do not periodically replace with the new pumping oil. Second problem for them is the poor design of the degassing furnaces. The temperature profile of the furnace is too poor and detection position of the temperature is not proper position in the furnaces. They well control of the degassing furnace by the control panel. They do not control the real temperature profile on the glass tubes. The glass tubes are the good thermal insulator that allows the blowing of the glass tubes with the holding by the hands. If you produce the FL tubes with the poorly maintained and designed pumping facilities, you never produce the reliable FL tubes. You must use the appropriate maintenance of the pumping facilities for the experiments and production. The poor maintenance of the pumping facilities is especially in China, even though they use the unnecessary expensive pumping facilities for the experiments and productions of the FL tubes.

By the use of the proper pumping facilities, we may study on the physical properties of the phosphor screens. We must know about negative electric charges on the individual phosphor particles in the phosphor screen for the control of the electric charges on the phosphor particles. The electric charges on and in the solids are not well studied with the difficulty on the quantitative study on the electrons in the solids. In this report, we will study the details of the intrinsic and extrinsic electric-charges of the phosphor particles in the phosphor screen of a lighted FL tube.

EXPERIMENTS

The commercial phosphor particles are always contaminated with (i) residuals of the by-products of the fluxes, (ii) interface layer of the by-products and host crystal, (iii) surface treatments, (iv) intentionally added binding materials, and (v) the adsorb gases from the air [15, 16, 17]. The contaminants on the surface of the phosphor particles are the solid electric insulators that generate the extrinsic charges on the phosphor screen. The extrinsic charges conceal the intrinsic charges in the phosphor particles. A scientific study must be made in the vacuum with the cleaned phosphor particles chemically and physically. We may clean up the surface of the commercial phosphor particles by the following processes.

We cannot use the phosphor powders that have the surface treatment by SiO_2 microclusters. So far as the surface of the phosphor particles is not contaminated with the SiO_2 microcrusters, the surface of the commercial phosphor particles should be cleaned by the etching of the surface layer of the phosphor particles by 10 % HNO_3 solution at first. The cleaned phosphor particles are rinsed with the deionized water several times. Then, the rinsed phosphor particles are stabilized with the 10 % H_3PO_4 solution. The stabilized phosphor powder rinses with the deionized water several times. The rinsed phosphor powder removes the water by the filter. The filtered phosphor particles dry in the heated oven at 110 ^oC for one overnight.

The phosphor screen was made with the dried phosphor particles by the sedimentation on the glass plate in the size of 9×10^{-4} m^2 {= 3×3 cm^2). The surface of the glass plates was covered with the electric-conductive indium-tin oxide (ITF) film. The anode voltages applied to the ITF films. The uniformity of the layers of the phosphor particles in the screens on the ITF film is not an important concern if the thickness of the phosphor screens is made with the layers less than 3 layers of the phosphor particles.

The intrinsic and extrinsic charges of the phosphor particles in the vacuum are invisible with the naked eyes. The existence of the electric charges on the phosphor screens in the vacuum encounters a difficulty for the quantitative determination of the electric charges. If the study is made with the FL tube, we never have the scientific study. The study on the FL tube may result in the poor reproducibility. We have found the electric charges on the phosphor screens can be quantitatively determined by the voltage dependence (VD) curves of the cathodoluminescence (CL) from the phosphor screen [15]. There is no commercial instrument for the determination of the VD curve of CL from the phosphor screens. We must have a hand-made device for the measurements of the VD curve of the CL. Figure 1 shows the photograph of the hand-made device for the study on the VD curves of the CL phosphor screens.

The pinholes in the phosphor screen do not influence to the determination of the VD curves of the CL phosphor screen. This is because the VD curves are given by the relative CL intensities from the given screen. We do not compare the CL intensities with the different phosphor screens. If the VD curves of the CL are obtained with the phosphor screen that contains the clumped phosphor particles less than 5 particles, we may use the phosphor screen for the determination of the VD curve. If the phosphor screens contain the clumped phosphor particles lager than 10 phosphor particles in the screen, the clumped phosphor particles influence to the VD curves of the CL. The phosphor screens should be made with the layers of the phosphor particles less than 3×10^{-2} kg m^{-2} (= 3 mg cm^{-2}).

The VD curves of the CL light intensities from the phosphor screen are obtained as a function of the accelerating voltage of the focused electron beam in a constant size. The VD curves of the CL are made with (a) the constant irradiation area (e.g., $1x\ 10^{-4}$ m^2 = 1 cm^2) on the phosphor screen and (b) the constant size of the electron beam (e.g., 1×10^{-6} A = 1 μA) on the given area of the phosphor screen under the accelerated voltages. The electron beam on the given phosphor screen was scanned with the NTSC (National Television System Committee). The beam sizes and irradiated area of the electron beam were changed by the accelerated voltages. The electron beam size and irradiated area on the phosphor screen with the given voltage had adjusted by the magnetic lens and deflection coil for each applied voltage. Adjustment of the both conditions was a tedious work. However, we obtained the fruitful results.

RESULTS AND DISCUSSIONS

The VD curves are sensitively changed with the surface conditions in the atomic sizes of the phosphor particles. The phosphor screens were made with screen density of 3 mg cm^{-2}, without any binder. We had detected two different VD curves from the phosphor screens. Figure 2 shows the typical VD curves of the CL from the phosphor screens in the wide voltage range between 10 V and 16,000 V. They are (a) the VD curve of the clean surface chemically, and (b) the VD curve of the CL of the commercial phosphor screens. The VD curves have the different threshold voltages, V_{th}, with the surface conditions. The VD curves at the voltages above 12 kV merge to the one VD curve.

If you study the surface conditions of the phosphor particles, you do not necessitate the VD curves of the CL in the wide voltage range shown in Figure 2. The VD curves with the narrow voltage range above V_{th} clearly show the electric conditions of the phosphor screens. Figure 3 shows the VD curves of the limited voltage range above the V_{th} of the low voltage CL phosphor screen (left curve) and contaminated commercial phosphor screen (right curve). As the CL phosphor particles in the phosphor screen have the clean surface, the VD curves of the CL are given by a linear function of the accelerated voltages above V_{th} = 110 V. Hereafter we call the phosphor particles, which have V_{th} = 110 V, as the low voltage CL phosphor particles. If the surface of the phosphor particles in the screen is contaminated with the electric insulators, the V_{th} of the VD curves of the CL shifts to 2000 V. Hence, we may distinguish the surface conditions of the phosphor particles by the VD curves at the narrow range above the V_{th}. As the CL phosphor particles have the clean surface, the VD curves of the CL have the V_{th} at 110 V. As the phosphor screens are made with the PL phosphor particles, the VD curves of the CL of the phosphor screen have the V_{th} at 2000 V. The difference comes from the luminescence mechanisms in the phosphor particles. The low voltage CL phosphor particles light up by the recombination of the pairs of the electrons and holes at the luminescence centers in the phosphor particles. The pairs of the electrons and holes are generated in the phosphor particles under irradiation of the electron beam. The PL phosphor particles light up by the direct excitation of the luminescence centers under the electron beam and the UV lights. If the surface of the CL phosphor particles is contaminated, the VD curves of the CL from the phosphor screen are controlled with the electric charges on the contaminated materials that have the V_{th} = 2 kV.

If the phosphor screens are made with the layers thicker than 5 layers, the V_{th} of the VD curves of the low voltage CL phosphor screens gradually shifts to the high V_{th} voltages up to the V_{th} = 2000 V. The contaminated phosphor screens do not change V_{th} = 2000 V with the screen thicknesses. Hence, we have a new tool for the study on the electric charges of the surface of the phosphor particles arranged at the top layer of the phosphor screens.

Prevention of clumped phosphor particles in phosphor screens

The electric charges on and in the phosphor particles in the FL tubes are invisible by the eyes. The phosphor producers had believed that the variation of the illuminance of the phosphor screens in the FL tubes comes from the pinholes and dark spots in the phosphor screen. The commercial phosphor powders usually contain the clumped phosphor particles. As the produced phosphor powders that have storage in the container or plastic bag usually contain the clumped phosphor particles. The clumped particles in the phosphor powders are caused with the adsorbed moisture from the air. Formation mechanisms of the clumped phosphor particles in the storage phosphor powders are below:

The narrow gaps between phosphor particles, less than 1 x 10^{-6} m, in the produced phosphor powder preferentially adsorb the moisture from air by the capillary condensation. The adsorbed moisture (water) in the gaps dissolves the contaminated materials on the surface of the phosphor particles. The concentrated solution in the gaps has the high surface tension. The solution in the gaps slowly extends on the entire surface of the phosphor particle. The wetted phosphor particles by the solution gather up with the neighbor wet phosphor particles. The gathered particles are the clumped particles. The sizes of the gathered particles are determined by the volume of the adsorbed water in the gaps between the particles and the dissolved contaminants in the water. The moisture of the storage container dries up by the formation of the clumped particles in the phosphor powder in the container. Practically, the number of the clumped phosphor particles in the storage container changes with (a) the conditions of the volume of the phosphor powder and (b) the size of the storage container.

For the prevention of the clumped phosphor particles in the storage phosphor powder in the container, it had found that the adhesion of the SiO_2 microclusters (gel) to the surface of the phosphor particles. The sizes of the gaps are significantly reduced by the adhesion of the SiO_2 microclusters on the phosphor particles, resulting in the small clumped particles in the storage of the phosphor powders. The addition of the SiO_2 microclusters has called as the surface treatment of the phosphor powders. The sizes of the clumped particles are changed with the procedures of the formation of the SiO_2 microclusters on the phosphor particles. The control of the clumped phosphor particles in the phosphor powders becomes the confidential of the phosphor producers. However, the engineers of the phosphor producers never calculate the effort of the surface treatment of the phosphor particles to the illuminance (lm m^{-2}) of the FL tubes.

We may statistically calculate the sizes of the clumped particles and the number of the pinholes and dark spots that may influence to the illuminance (lm m^{-2}) of the lighted FL tubes. The average particle size of the phosphor particles is 5×10^{-6} m (= 5 μm). As the clumped particles are composed with 10 phosphor particles, the size of the clumped particles is 1×10^{-5} m (= $10^{-1/3} \times 5 \times 10^{-6}$ m = 10 μm). If the clumped particles are gathered with 100 particles, the size of the clumped particles is 2.3×10^{-5} m (= $100^{-1/3} \times 5 \times 10^{-6}$ m = 23 μm). The typical commercial 40W-HCFL tube has the inner diameter 3×10^{-2} m (T-10) and 1.0 m long. The inner surface area of the 40W-HCFL is calculated as 0.1 m^2 (= 100 cm^2). We may take the area of the phosphor screen as the inner surface area of the FL tube that is 0.1 m^2. If the phosphor screen of the 40W-HCFL tube contains 100 pinholes in the size of 2.3×10^{-5} m, total area of the pinholes in the phosphor screen is 5×10^{-8} m^2 $\{= (2.3 \times 10^{-5}\ m)^2 \times 10^2\}$. With 1000 pinholes (including dark sports) in the phosphor screen, total area of the pinholes is 5×10^{-7} m^2. The calculations clearly indicate that the 1000 pinholes and dark spots (5×10^{-7} m^2) in the phosphor screen of the 40W-HCFL is negligibly small as the compared with the area of the phosphor screen (0.1 m^2). The calculations clearly indicate that the pinholes and dark sport in the phosphor screen of the FL tubes is not an important subject. The detected variation of the illuminance (lm m^{-2}) of the phosphor screens in the produced FL tubes is not by the dark spot and pinholes in the phosphor screen. The variation in the illuminance (lm m^{-2}) of the produced FL tubes comes from the electric charges on the phosphor particles, which have ever reported in the study on the FL tube.

The pine-holes and dark spots in the phosphor screens are visible by the naked eyes that are the concrete materials. The attention to the concrete materials has overlooked the important subject in the study on the production of the FL tubes. The concealed important factor in the past is the formation of the gap between positive column and phosphor screen [14]. The gap between phosphor screen and positive column in the FL tubes is invisible by the naked eyes. The study on the depth of the gaps in the lighted FL tubes is abstraction that is thinking by the brain. The thinking results must prove with the experiments that are indirectly prove the existence. The depths of the gap can be quantitatively detected and evaluated from the measurement of the build-up curve of the illuminance or luminance of the FL tube by use of the Ulbricht Sphere [14]. Now we can quantitatively study on the electric charges on the phosphor particles that have the clean surface.

Formation of SBE on solids of electric insulator

If you measure the VD curve of the CL from the phosphor screens of the commercial CL and PL phosphor powders, you will only obtain the VD curve of the contaminated phosphor screen in Figure 3. The contaminations of the surfaces of the commercial phosphor particles are (a) the incomplete production process of the phosphor powders as the material science, (b) the surface-treatment by the SiO_2 microclusters of the electric insulator, and (c) the deliberately-added solid binders of the low melting temperatures. All contaminants on the surface of the phosphor particles are the electric insulators. First, we have studied the VD curve of the CL that has the V_{th} is 2000 V.

As the first electron penetrates in the solids of the electric insulator, the incident electron collides with the atoms at the lattice sites. The collided atom at the lattice site ionizes by the release of the free electron into the vacuum between lattice sites, leaving a hole in the atom (a vacancy of electron) at the lattice sites. The released electrons from the atoms at the lattice site are called as the secondary electrons. The secondary electrons in the surface volume in the depth of 10^{-10} m (= 10 Å) from the surface of the solid particle may escape from the solids into the vacuum as illustrated in Figure 4 (A). The positive electric field from the hole in the surface volume of the solids extends to the vacuum. The positive electric field from the hole in the surface volume attracts the free electron in the vacuum. The attracted electron in the vacuum cannot penetrate into the solid. The attracted electron stays in the front of the surface of the solid with the distance at 5×10^{-6} m (= 5 μm) above the solids. The electron in the vacuum is strongly bound with the hole in the surface volume of the solid. The bound electron in the vacuum is the surface-bound-electron (SBE) in front of the surface of the solid as illustrated in Figure 4 (B) [15].

The individuals of the host crystals of the PL phosphor particles are essentially electric insulators. The irradiated surface area of the PL phosphor particle is instantly shielded by the electric field from the SBE. Consequently, the surface of the phosphor particles at the irradiation side is electrically shielded by the electric field from the SBE, F_{SBE}. Subsequent electrons, which approach to the phosphor particles, receive the strong Coulomb's repulsion from the SBE on the surface of the phosphor particles. The negative potential of the SBE is estimated from the V_{th} of the VD curve of the CL. It is 2000 eV. The formation of the SBE restricts on the exposure side of the electric insulator with the reason that the holes in the surface volume of the electric insulators do not move in the positions. The formation of the SBE on the pure PL phosphor particles is limited to the surface volume that exposes to Ar gas space. Figure 5 illustrates the phosphor particle that is electrically shielded by negative charges of the SBE at only exposure side. As the electrons from the cathode have the kinetic energy above 2000 V, the electrons may penetrate through the F_{SBE}. The incident electrons may penetrate into the electric insulators. If the electric insulator contains the luminescence centers that are the PL phosphor particles, the penetrated electron in the PL phosphor particles may have the chance to activate the luminescence centers for the generation of the CL.

As the surface of the phosphor particles is contaminated with the layer of the thin insulator, the thin contaminated layer is also electrically shielded by the F_{SBE}. If the surface of the phosphor particles is contaminated with the SiO_2 microclusters, the microclusters are the pure electric insulator. The surface of the SiO_2 microclusters is electrically shielded with the F_{SBE}. The intensity of the F_{SBE} on the SiO_2 microclusters is the same with the F_{SBE} of the pure PL phosphor particles. Figure 6 illustrates the shielded phosphor particle by the F_{SBE} on the SiO_2 microclusters. The commercial PL phosphor particles always have the surface treatment with the SiO_2 microclusters for the protection of the clumped phosphor particles by the adsorbed moisture from the air. So far as we use the pure PL phosphor powders, we cannot study the difference of the VD curves of the CL from the phosphor screen with the clean and contaminated phosphor particles.

For the example, the phosphor screens in the lighted FL tube before 1975 were made with the $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn white emitting phosphor particles. The luminescent centers of this phosphor particle are only directly excited by the incident electrons or the 254 nm UV lights [15, 16, 17]. The VD curve of the phosphor screen of the cleaned surface of $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn phosphor particles has the V_{th} at 2 kV. As the phosphor screen is made by the contaminated $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn phosphor particles, the VD curve of the CL from the phosphor screen has the same $V_{th} = 2$ kV. With the experimental results by the $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn white emitting phosphor screen, the scientists and engineers of the FL tubes paid their attentions to the removals of the pine-holes and dark spots of the phosphor screens in the FL tubes to improvement of the illuminance ($lm\ m^{-2}$) from the phosphor screens by the try and error approach. Their trials led them to a wrong direction of the study on the phosphor screen in the FL tubes by the surface treatments of the phosphor particles, as already described.

Determination of depths of gap in lighted FL tubes

If the phosphor screen in the FL tubes is made by the $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn phosphor particles that have the clean surfaces, the surface of the phosphor screen in the lighted FL tubes is covered with the negative electron cloud of the F_{SBE}. The moving electrons in the Ar gas space are mainly controlled by the longitudinal vector electric field, F_{vec}. The approaching electrons to the phosphor screen receive the strong Coulomb's repulsion from the F_{SBE} on the phosphor screen. The moving electrons could not reach on the surface of the phosphor screen. The repulsed electrons move on in the Ar gas space that is defined by $F_{vect} \geq F_{SBE}$. The defined Ar gas space by the $F_{vect} \geq F_{SBE}$ has called as the positive column. The moving electrons in the positive column generate the UV lights. The phosphor screen transduces the UV lights to the lights in the visible spectral wavelengths. The FL tubes inevitably have the gap between positive column and phosphor screen. The depth of the gap is precisely determined from the build-up curve of the illuminance ($lm\ m^{-2}$) in the Ulbricht Sphere [3]. The determined depth of the gap of the commercial 40W-HCFL tubes is 4×10^{-3} m (= 4 mm). The deep gap has determined the diameter of the commercial FL tubes. The outer diameter of the commercial 40W-HCFL tube has been empirically determined as 3.2×10^{-2} m (T-10).

The light of the FL tubes are generated by the excitation of Hg atoms in the volume of the positive column in which the electrons move on in the defined volume by the $F_{vect} \geq F_{SBE}$. We may calculate the real diameter of the positive column in the commercial 40W-HCFL tube in 3.2×10^{-2} m outer diameter. Since total thickness of the glass tube is 2×10^{-3} m, the inner diameter of the glass tube is 3.0×10^{-2} m. Total depth of the gap is 8×10^{-3} m (= $4 \times 2 \times 10^{-3}$ m). The diameter of the positive column is 2.2×10^{-2} m {= $(3.0 - 0.8) \times 10^{-2}$ m} (= 2.2 cm). The ratio of the diameter of the positive column to the inner diameter of the glass tube is 0.73 (= 22×30^{-1}). If one considers the ratio of the diameters (0.73), he may have a conclusion that the gap is not largely influence to the illuminance (lm m^{-2}) of the lighted FL tube. His conclusion is an incorrect answer. If one calculates the ratio of the volume of V_{pos} to the volume of V_{Ar}, he may find that the depth of the gap significant influence to the illuminance (lm m^{-2}) of the lighted FL tubes.

The volume of the Ar gas space per unit length of the 40W-HCFL tube (1 m) is calculated as $V_{Ar} = 7.0 \times 10^{-4}$ m^3 {$= \pi \times (\varphi/2)^2 = 0.78 \times \varphi^2 = 0.78 \times (3.0 \times 10^{-2})^2$}. The volume of the positive column per unit length is $V_{pos} = 3.8 \times 10^{-4}$ m^3 {$=0.78 \times (2.2 \times 10^{-2})^2$}. The volume of the gap per unit length is given by $V_{gap} = V_{Ar} - V_{pos}$ that is 3.2×10^{-4} m^3 {$= (7.0 - 3.8) \times 10^{-4}$ m^3}. The ratio of ($V_{pos} \times V_{Ar}^{-1}$) is 0.54 ($= 3.8 \times 7.0^{-1}$). The ratio of ($V_{gap} \times V_{Ar}^{-1}$) is 0.46 ($= 3.2 \times 7.0^{-1}$). The volume of the V_{pos} is nearly equal with the volume of the V_{gap}. Here we have paid our attention to the optical absorption of the UV lights by the unexcited Hg atoms in the Ar gas space of the gap. The gap contains the 46 % of the evaporated Hg atoms in the total Ar gas space of the FL tubes. The 46 % of the unexcited Hg atoms in the gap optically absorb the UV lights from the positive column before reaching to the phosphor screen. The quantitative calculations of the optical absorption of the UV lights by the unexcited Hg atoms in the gap had overlooked in the study on the FL tubes in the past, because the presence of the gap is invisible by the naked eyes. We may calculate quantitatively the demerit of the gap in the lighted FL tubes.

The unexcited Hg atoms in the gap efficiently absorb the emitted UV lights from the positive column before reaching to the phosphor screen. By the presence of the gap in the depth of 0.004 m, the excitable Hg atoms in the positive column are 54 % in the evaporated Hg atoms in total Ar gas space. The emitted UV lights from the 54 % Hg atoms in the positive column are absorbed by the 46 % of the unexcited Hg atoms in the gap. The UV intensity on the phosphor screen in the lighted FL tubes is equivalent to 29 % {$= 0.54 - (0.54 \times 0.46) \times 100 = (0.54 - 0.25) \times 100$}. The UV intensity on the phosphor screen is equivalent with only 29 % of the Hg atoms of the total evaporated Hg atoms in the total Ar gas space. The light of the commercial 40W-HCFL tubes with the phosphor screen of $Ca_3(PO_4)_4(F,Cl)$:Sb:Mn PL white emitting phosphor screen corresponds to the lights from 30 % of the evaporated Hg atoms. If the lighted FL tube does not have the gap, or the depth of the gap shallower than 1×10^{-4} m, the illuminance from the phosphor screen in the lighted 40W-HCFL tube will goes up to 3 times from the illuminance of the current 40W-HCFL tubes with the $Ca_3(PO_4)_4(F,Cl)$:Sb:Mn phosphor screen. The calculations inform us the important subject of the improvement of the illuminance from the current 40W-HCFL tubes. The urgent subject is the eradication of the gap or significant reduction of the depth of the gap between positive column and phosphor screen. The depths of the gap are determined by the electric field F_{phos} from the charged phosphor screen.

The $Ca_3(PO_4)_3(Cl, F)$:Sb:Mn phosphor screens, which generate the deep gap in the lighted FL tubes, are only applicable to the FL tubes in the outer diameters wider than 3.2×10^{-2} m (T-10). The unexcited Hg atoms in the gap absorb the UV light generated in the positive column before reaching to the phosphor screen. The quantitative calculations that the UV lights reach on the phosphor screen is given in the reference [13]. The FL tubes narrower than 10 mm (T-3) cannot made by the phosphor screen of the $Ca_3(PO_4)_3(Cl,F)$:Sb:Mn phosphor particles [15, 16, 17, 18].

As the summary of this Chapter, the amount of the SBE on the PL phosphor screen is nearly constant with and without SiO_2 microclusters. The constant amount of the SBE on the phosphor particles can be detected by the measurements of the VD curve of the the CL of the phosphor screen with the various contamination levels. The V_{th} at 2000 V of the VD curves does not change with the amount of the insulator particles. This is because the formation of the SBE is limited on the exposure side of the surface of the phosphor particle to Ar gas space as illustrated in Figure 6. The depth of the gap between positive column and phosphor screen does not changed with the variation in the contamination levels of the phosphor particles.

Neutral surface of low voltage CL phosphor particles

The low voltage CL phosphor screen has the $V_{th} = 110$ V, indicating that the SBE does not form on the surface of the low voltage CL phosphor particles in the vacuum. The phosphor particles naturally emit the secondary electrons into vacuum from the surface volume as illustrated in Figure 4. The luminescent centers of the low voltage CL phosphor particles are the recombination centers of the pairs of the electrons and holes, which are generated in the phosphor particles. The number of the electrons and holes generated in one phosphor particle is around 10^2 pairs, depending on the energy of the penetrated electrons. The capture of the free electron at the given luminescence centers triggers the luminescence process. The trapped electron in the luminescence center attracts the hole, which distributes at around the luminescence center. The attraction force F to the hole is given by

$$F = Q^2 l^{-1} \qquad (1)$$

Where Q is electric charge and l is the distance between electron and hole. The Q is the constant in the lighted FL tubes. The value of F is inverse function of l. The distance between the hole in the surface volume of the phosphor particle and SBE (l_{SBE}) is $l_{SBE} = 5 \times 10^{-6}$ m. The distance between the hole and the trapped electron in the luminescence center in the phosphor particles (l_{trap}) is calculated from the distance between lattice sites in the crystal and mole concentrations of the luminescence centers. Assuming that the average distance between lattice sites is 5×10^{-10} m (=5 Å) and the concentrations of the luminescence center is 5 mole %. The average distance between the luminescence centers in the low voltage CL phosphor particles is 20 lattice sites (= 100/5), corresponding to 1×10^{-8} m (= $5 \times 10^{-10} \times 20$ m). The trapped electron in the luminescence center attracts the hole at the maximum lattice sites at 10 lattices, corresponding to the distance $l_{trap} = 5 \times 10^{-7}$ m (= 0.5 μm). Since ($l_{trap} = 0.5$ μm) << ($l_{SBE} = 5$ μm), the electrons trapped in the luminescence centers in the phosphor particle attract the holes in the surface volume in the low voltage CL phosphor particles. The attracted holes recombine with the trapped electrons at the luminescence centers. Consequently, the holes in the surface volume of the low voltage CL phosphor particles disappear from the phosphor particles. The SBE loses the binding partner and become free electrons in the vacuum. Figure 7 schematically explains the mechanisms described above. Thus the low voltage CL phosphor particles do not have the electron on the surface of the phosphor particle during the lighting. The lighted phosphor particles have the neutral surface electrically. This is the reason that the phosphor screens of the high resolution CRTs are produced by the low voltage CL phosphor powder, having V_{th} = 110 V. Figure 8 shows the photograph of the miniature CRT that has the screen area in 1×10^{-4} m^2. Figure 9 shows the photograph of the images of 307,200 pixels on the neutralized Y_2O_2S:Tb phosphor screen [19]. The smeared images on the photograph in Figure 9 are caused with the grain size of the photo-film. The real images on the phosphor screen are clear under the magnified lens (x 3). The high resolution images on the miniature CRT may prove the complete removal of the surface charge on the phosphor screen by handling of the production process of the Y_2O_2S:Tb phosphor powder. If you make the phosphor screen with the commercial Y_2O_2S:Tb phosphor powder, you never have the clear images on the phosphor screen of the miniature CRT. The commercial phosphor powders from Japan never make the sharp images on the phosphor screen with the reasons that the phosphor particles heavily contaminated with the residuals of the by-products. The sharp and clear images on the screens of the color CRT had also proved the color CRTs made in Korea that I had consultant. The Korean monitor CRTs sold with the price of 3 times of the price of the made-in Japan. The US customers chose the Korean monitor CRTs. The results indicate the customers take the image quality than the price. The protection of their eyes is the most important concern. The Japanese producers did not find the reason of the sharp images on the phosphor screen. The reason is the electric charges on the phosphor screen. The Japanese Government and industries changed the broadcasting system as the digital from the analogue. The digital image can be observed by the LCD screens, rather than the CRTs. The same story can apply to the developments of the lighting sources, like as the FL tubes. We must have the good understanding on the mechanism of the no-formation of the SBE on the low voltage CL phosphor particles for the development of the reliable FL tubes.

The theoretical V_{th} of the low voltage CL phosphor particles should be $3E_g$ [15], where E_g is band gap of the host crystal. ZnO:Zn and ZnS:Cu: Al phosphor particles respectively have E_g = 3.3 eV and E_g = 3.8 eV. The $3E_g$ are respectively 10 eV and 11 eV. We have the VD curve of those phosphor screens that have the $V_{th} \approx 10$ V. Those phosphor particles do not have the trapped electrons at the room temperatures; e.g., ~25°C. ZnS:Cu:Al phosphor particles cannot apply to the phosphor screen that make the chemical reaction between S and Hg vapor to form HgS in the Ar gas space.

Many low voltage CL phosphor particles have the trapped electrons at the luminescence centers at the room temperatures. We obtained the V_{th} at 110 V with those low voltage CL phosphor particles. The studies on the miniature CRT may support this conclusion. Typical low voltage CL phosphor particles with V_{th} = 110 V are Zn_2SiO_4:Mn, Y_2O_2S:RE, and Y_2O_3:RE phosphors, where RE is Eu, or Tb, Dy, and Sm [15, 16, 17].

Hysteresis curve of low voltage CL phosphor screen

The V_{th} = 110 V of the low voltage CL phosphor particles is attributable to the trapped electrons at the luminescence centers. At the room temperature, the luminescence centers hold the trapped electrons in it. When the VD curve of those phosphor screens has carefully studied at around V_{th}, the VD curve exhibits a hysteresis in a narrow voltage range just above V_{th} [15]. Figure 10 shows the hysteresis curve of Y_2O_3:Eu red phosphor screen. The phosphor screen is on the electric conductive layer of the tin oxide (TO) or indium tin oxide (ITO), which has the anode potential. The hysteresis curve is obtained as followings. When -150 V once applies to the ITO layer (anode), the phosphor particles in the screen exhibits the negative potential by the trapped electron at the luminescence centers. Then the positive potential applies to the ITO layer. The applied positive potential gradually increases from 100 V, the CL light suddenly appear at +190 V. The CL intensity sharply goes up to the linear curve that the VD curve of V_{th} = 110 V as shown in Figure 10. Then the applied voltage at the ITO layer gradually decreases from 250 V, the CL light intensities very slowly go down until 115 V. The CL intensity sharply down to zero at 110 V. Many low voltage CL phosphor screens have the hysteresis curve shown in Figure 10. The hysteresis curve is repeatable after the application of -150 V to the ITO layer. The storage CRT practically utilizes the hysteresis shown in Figure 10. There is the explanation of the hysteresis curves by the secondary electron emission from the phosphor screen. The explanation is the lack of the mechanisms of the generation of the secondary electrons from the solids [15]. The commercial storage CRT uses the low voltage CL of the Zn_2SiO_4:Mn phosphor screen.

The followings explain the mechanisms of the hysteresis curve. Once the phosphor screen emits the CL lights, the incident electrons in the voltages from 250V to 115V generate many pairs of electrons and holes in the phosphor particles. The phosphor particles hold the neutral surface. As the kinetic energy of the incident electrons is below 115V, the incident electrons do not generate the pairs of the electrons and holes in the phosphor particles. Then the trapped electrons at the luminescence centers do not have the recombining partner of the holes. The luminescence centers hold the trapped electrons. As the consequence, the surface of the phosphor particles has the negative electric field by the trapped electrons. The incident electrons cannot approach to the phosphor particles by the Coulomb's repulsion from the negative field.

This is a reason that the low voltage CL phosphor screen has the hysteresis curve by the eradication of the trapped electrons at the luminescent centers in the lighted phosphor screen. The trapped electrons can be eradicated by either (a) application of + 200 V to the ITO layer or (b) irradiation of the strong UV lights on the phosphor screen. The storage CRT tube utilizes the hysteresis curve. The human body usually has the static electricity of above 200 V, and sometime is 2000 V. If your fingers touch on the face plate of the unlighted phosphor screen of the storage CRT, the phosphor screen of the touched areas emits the CL lights, indicating the elimination of the trapped electrons in the phosphor screen. The experimental results of the storage CRTs give us the fundamentals of the electric properties of the phosphor screens of the low voltage CL phosphor powders. The results are applicable to the phosphor screens in the lighted FL tubes.

Moving electrons on phosphor screen in different electric fields

We now know the phosphor screens in the FL tubes have the different conditions of the electric charges, depending on the production processes. For the analysis of the moving electrons in the phosphor screen in Ar gas space, we like to know the moving electrons on the different potentials on the surfaces of the phosphor screens in the lighted FL tube. Figure 11 shows the experimental configurations. The electric potentials of the surface of the phosphor screens are controlled by the changes of the electric potentials on the conductive indium-tin oxide (ITO) film on the phosphor screens. The electrons (dark circle at left side) take out from the needle cathode. The taken electrons move on from the needle cathode to the plate anode under the F_{vect}. Figure 11 (A) is the ITO film on phosphor screen is equal potential with the cathode. Figure 11 (B) is ITO film on phosphor screen has positive potential at +110V. And Figure 11 (C) ITO film on phosphor screen has negative potential at -110 V. The ITO film shields the phosphor screen. Then, the moving electrons in Ar gas space are not influenced by the charges on the phosphor screens in the FL tubes. The moving electrons are influenced by the electric potential of the ITO films. The ITO films have (a) neutral, (b) positive, and (c) negative potentials. The electric current in the ITO film is detected at the lead wire between the ITO film and DC power source of the positive and negative terminals. If the Ar atoms in the Ar gas space are excited by the moving electrons, the sky-blue lights are observed by the naked eyes.

As the potential of the ITO film is zero (cathode potential or grand potential), the electrons from the needle cathode preferentially take the surface conduction on the neutral potential of the ITO film. The electrons from the cathode are collected by the anode. No electric current in the ITO film is confirmed by the detection of the electric current in the ITO film. The electrons on the surface conduction under the F_{vec} do not have the chance to collide with the Ar atom, resulting in no light in the device. The calculated probability that the electron moves on longitudinal electric field meet an Ar atom is 10^{-7} atom. The calculated result has been proved by the experimental result.

When the ITO film has positive potential (+ 110 V), the ITO film collects all electrons from the cathode, so that the ITO film has the electric current. The electric current in the ITO film is detected by a current meter between ITO film and the electrode of the DC power supply. No light is generated in the Ar gas space.

As the negative potential (- 110 V) applies to the ITO film, the electrons from needle cathode receive the Coulomb's repulsion from the negative field of the ITO film. The repulsed electrons stay and form the positive column in the Ar gas space. The moving electrons in the positive column have the chance to excite Ar atoms for the sky-blue lights. Naturally, the gap between the positive column and ITO film that has the negative potential (-110V). The electrons from cathode are collected by the plate anode. The Ar atoms in the Ar gas pace in the positive column emit the sky-blue lights. The experimental results give the condition of the phosphor screen of the ordinarily lighted FL tubes. The phosphor screen in the lighted FL tubes must have the SBE on the phosphor screen for the excitation of the Ar (and Hg) atoms. The lighted FL tubes have studied with the deep gaps for more than 80 years. However, the light-outputs of the lighted FL tubes are sensitively controlled by the depths of the gap. For the improvement of the illuminance (lm m^{-2}) of the given FL tubes, we must find out how do control the moving electrons on the conditions of the phosphor screens. The study on the control of the depth of the gap by the arrangement of the phosphor screens is underway.

CONCLUSION

The intrinsic and extrinsic electric charges on the surfaces of the phosphor particles in the vacuum devices have been studied by the voltage dependence (VD) curves of cathodoluminescence (CL) from the phosphor screens. The electric charges on the phosphor particles can be distinguished by the threshold voltages (V_{th}) of the VD curves of the CL. The commercial CL and PL phosphor powders, which are heavily contaminated by the insulator particles, have V_{th} = 2 kV, which are caused by the surface-bound-electrons (SBE) on the insulator particles. The approaching electrons to the phosphor screens receive the Coulomb's repulsion from the SBE on the phosphor particles. The lighted FL tubes inevitably have the deep gap between positive column and phosphor screen by the SBE. The studies have found an exception. The low voltage CL phosphor screens, which the threshold voltage of the VD curves of CL is 110 V, do not have the SBE. The V_{th} = 110 V is caused by the trapped electrons in the luminescence centers. In the lighted phosphor screen, the trapped electrons disappear from the phosphor particles. The phosphor screen by the low voltage CL phosphor particles has the electrically neutral surface in the lighting time. However, it has experimentally found that the electrons selectively take the surface conduction on the electrically neutral phosphor screen. The moving electrons on the surface conduction of the phosphor screen do not meet with the Ar atom. The moving electrons in the positive column require the scattering by the Coulomb's repulsion from the phosphor screen. The optimized structure of the phosphor screens in the coil-EEFL tubes, which have $W_{act} \approx 0$, is under the studying.

The author is old (83 years) but he like to help someone who interest of the development of the $W_{act} \approx 0$ with the improved illuminance (lm m^{-2}) of the coil-EEFL tubes. Please contact him if you have the interest of the project for the contribution to the green energy project on the world.

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Figures

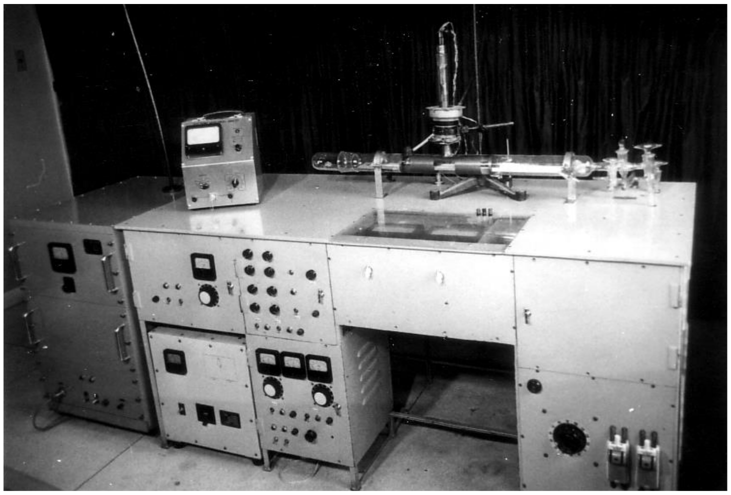


Figure 1 Photograph of hand-made device for study on voltage dependence curve of CL

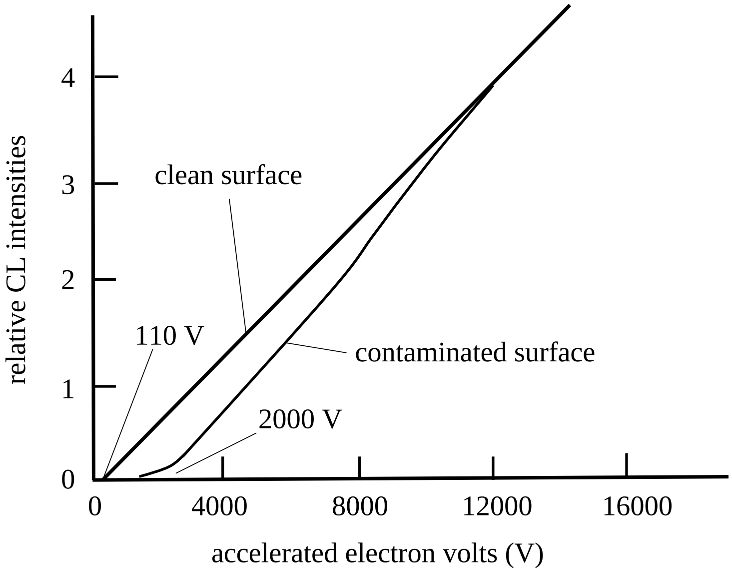


Figure 2 Voltage dependence of CL phosphor screens as function of applied voltages

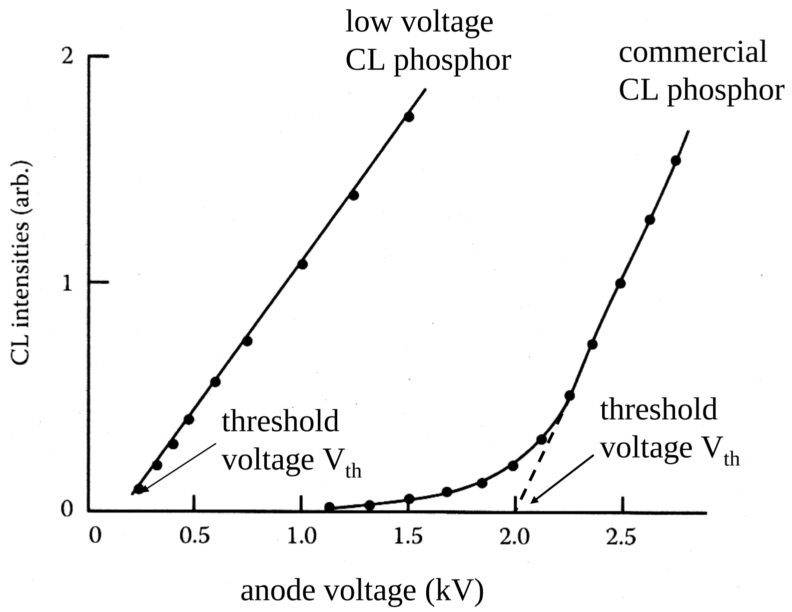


Figure 3 Voltage dependence curves of low voltage CL phosphor screen (left side) and contaminated commercial CL phosphor screen (right side)

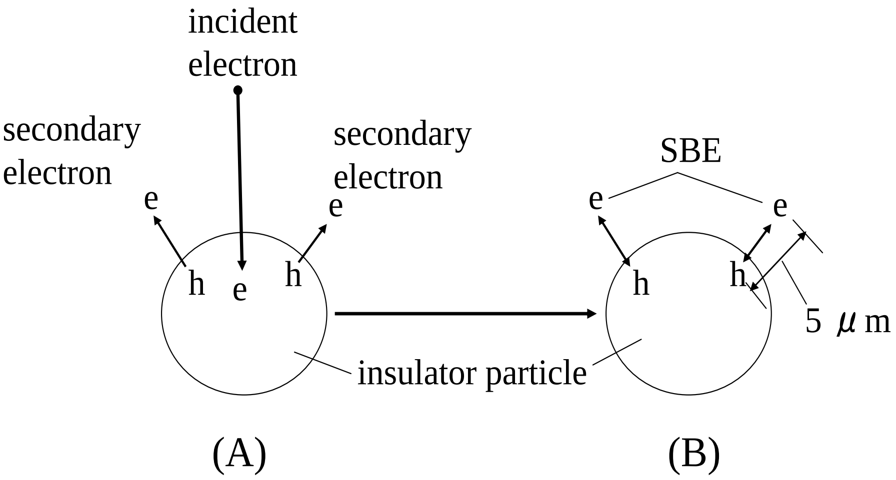


Figure 4 Schematic illustration of formation of SBE in front of insulator particle

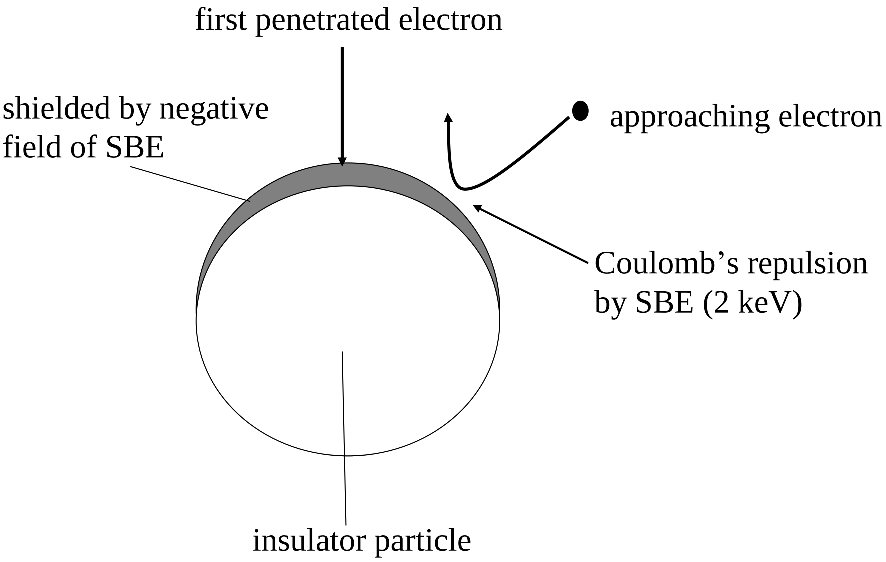


Figure 5 Schematic illustration of insulator particle shielded by SBE. Approaching electrons receive Coulomb’s repulsion from SBE.

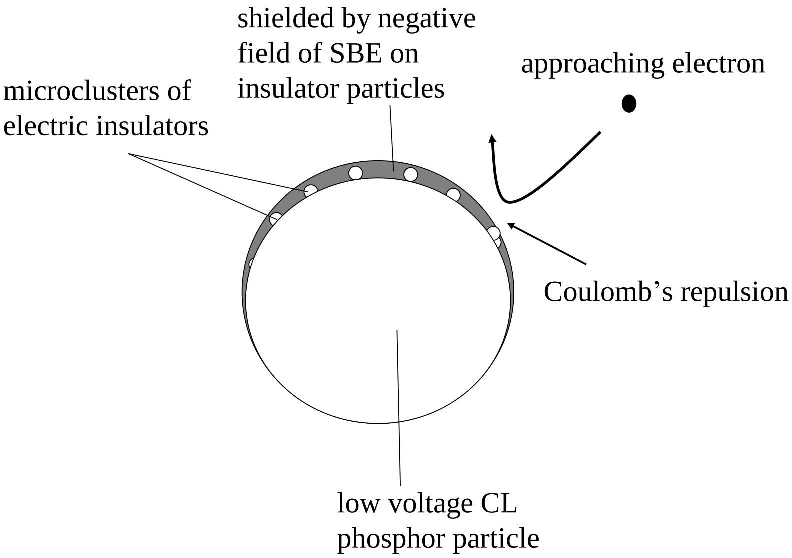


Figure 6 Schematic illustration of phosphor particles of which surface is contaminated with microcrusters The microcrusters are instantly charge up by SBE and then phosphor particles are shielded by negative charges of SBE.

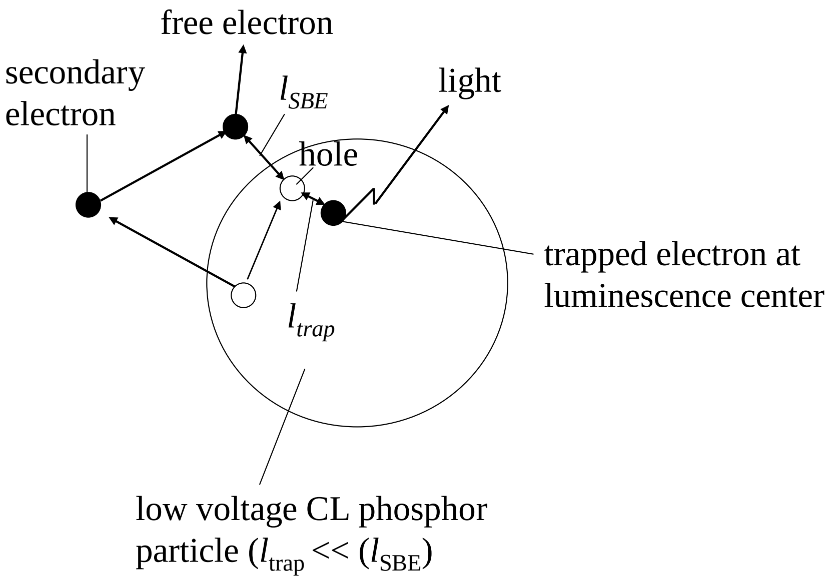


Fig. 7 Explanation of no formation of SBE on surface of low voltage CL phosphor particles

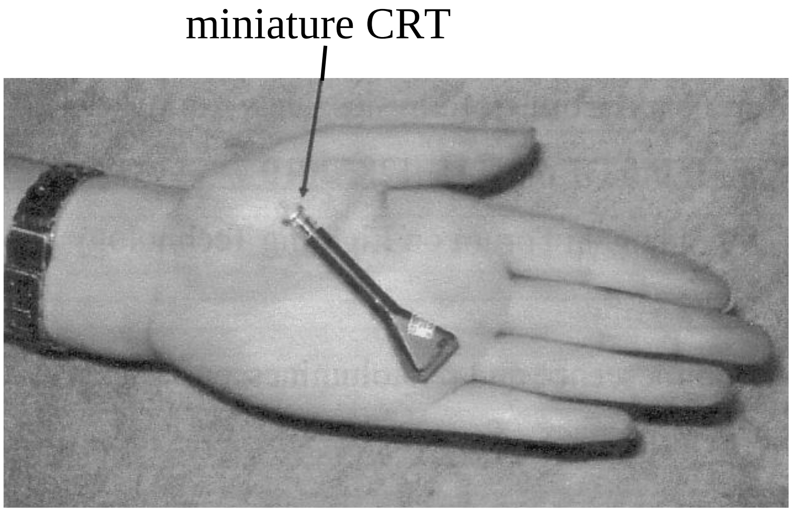


Figure 8 Photograph of miniature CRT in the screen size of 1 x 10^{-4} m^2

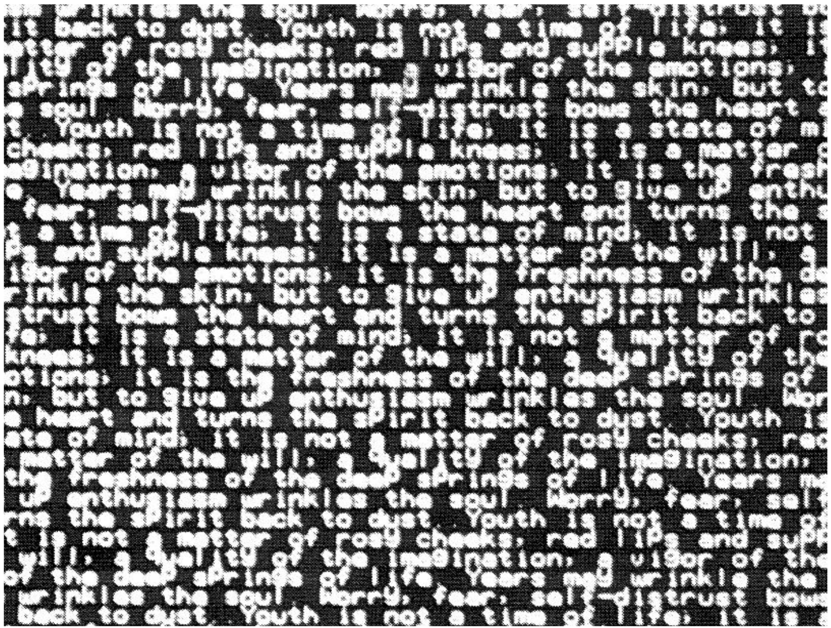


Figure 9 Photograph of 307,200 pixels on phosphor screen in size on 1 cm^{-2}

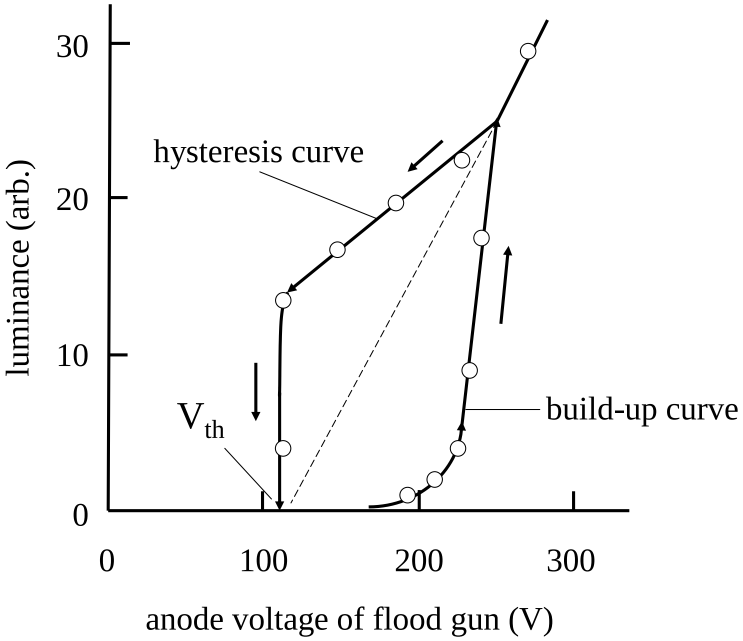
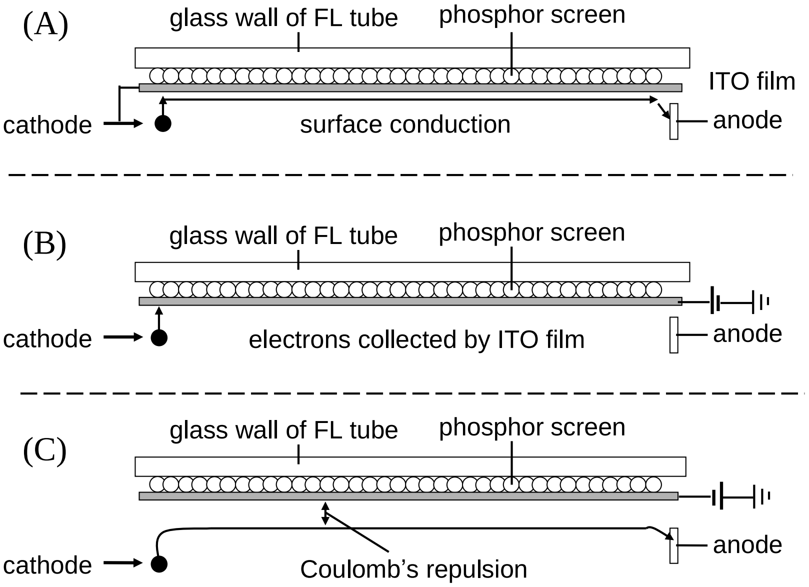


Figure 10 Hysteresis curve of Y_2O_3:Eu phosphor screen which appears at near voltage range above V_{th}



[6] ***Figure 11 Experimental configurations of electric potentials on phosphor screens which have layers of optically transparent and electric conductive layer of tin-oxide (ITO) films***