Field Emission Lighting

Transparent Conductive Layer

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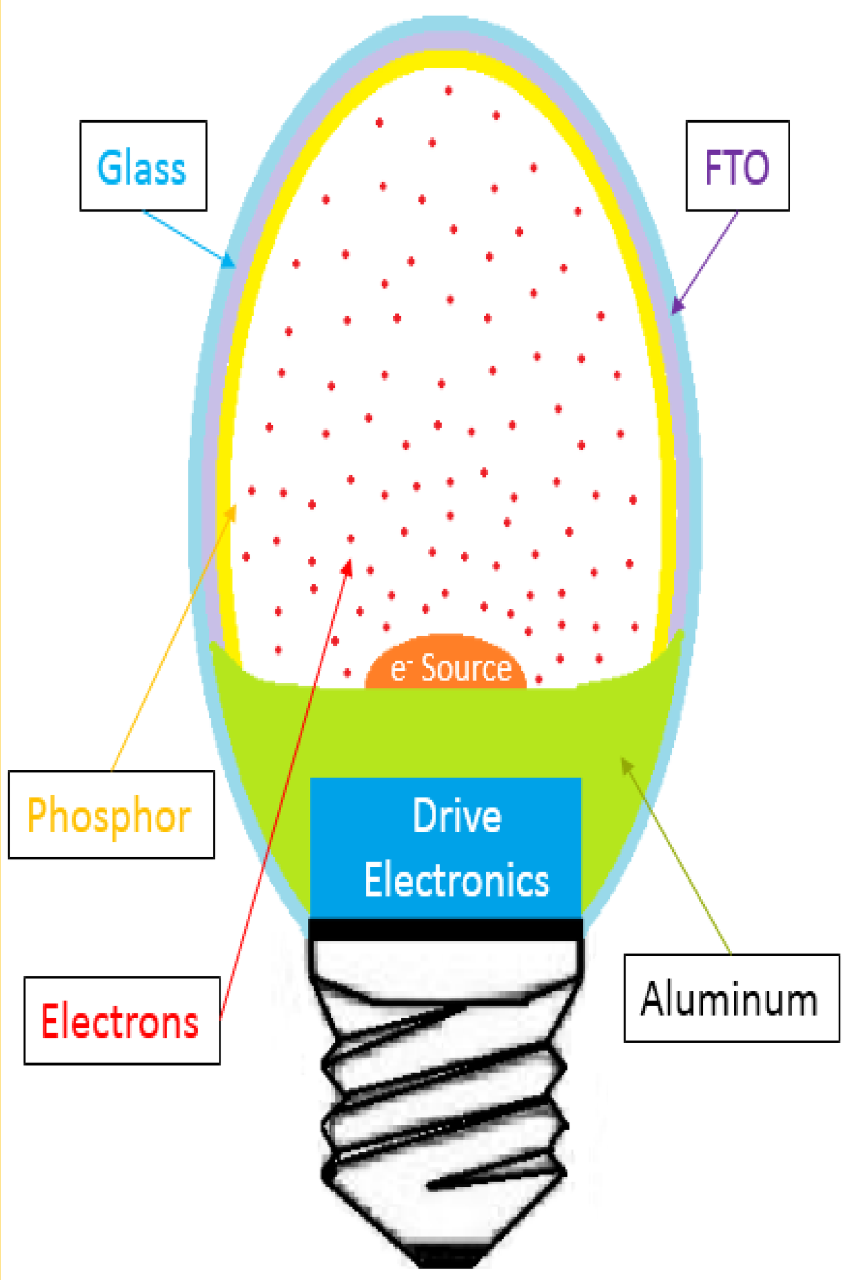
Introduction

- Field Emission Lamps (FEL) are based on phosphors which are not good conductors (both electrically and thermally). This necessitates a conductive layer that is also transparent to visible spectrum.
- Most commonly used Transparent Conductive Oxide (TCO) is Tin doped Indium Oxide (ITO, $Sn:In_2O_3$).
- Indium's scarcity (≈ 1-100 ppm from ZnS ores) and increasing price (≈ $600-750/kg) is a serious problem.
- Fluorine-doped Tin Oxide (FTO) is composed of sustainable elements and has similar transparency and considerable conductivity (> 10^3 S/cm).
- Tunability of Transmittance and Conductivity by varying Fluorine doping in Tin Oxide is possible to a large extent.
- Other candidates could be ZnO based TCOs such as Fluorine doped ZnO or Aluminum doped ZnO.



High Color Quality: CRI > 90,

Energy Efficient: LER > 70 Lumens/W,

Durable ~ 6000 hours of operation,

Mercury-free,

Sustainable (No Indium, Gallium etc.),

Bright(>10000 Cd/m^3) and fully dimmable,

Adjustable Color Temperature (CCT),

Reasonable cost ($ 10-20) for an Edison shaped light bulb.

Motivation

- Use of FTO as a heat sink (anode) layer without compromising optical transparency is the main target.
- Use of low-cost fabrication techniques such as spray pyrolysis, and sol-gel coating.
- Better understanding of TCO layers by studying structural effects, film thickness and fabrication conditions with respect to FEL characteristics.

$$\frac{\kappa}{\sigma} = LT$$

κ, σ : thermal, electrical conductivity

T: temperature, L: a constant

Comparison of Transparent Conductors

Property	Material
Highest transparency	ZnO:F, Cd_2SnO_4
Highest conductivity	In_2O_3:Sn
Lowest plasma frequency	SnO_2:F, ZnO:F
Highest plasma frequency	Ag, TiN, In_2O_3:Sn
Highest work function, best contact to *p*-Si	SnO_2:F, $ZnSnO_3$
Lowest work function, best contact to *n*-Si	ZnO:F
Best thermal stability	SnO_2:F, TiN, Cd_2SnO_4
Best mechanical durability	TiN, SnO_2:F
Best chemical durability	SnO_2:F
Easiest to etch	ZnO:F, TiN
Best resistance to H plasmas	ZnO:F
Lowest deposition temperature	In_2O_3:Sn, ZnO:B, Ag
Least toxic	ZnO:F, SnO_2:F
Lowest cost	SnO_2:F

R. G. Gordon, "Criteria for Choosing Transparent Conductors," *MRS Bulletin*, (2000) vol. 25, pp. 52-57.

Figure of Merit for TCOs

$$\text{FOM}=\frac{T^q}{R_\square}=T^q*\sigma*\text{d}$$

T: transmittance

q: a number (10,20 or 100)

$R_\square$: sheet resistance

σ: conductivity

d: film thickness

Our Goal: Increasing the electrical conductivity as much as possible without compromising from optical transmittance (T>85%).

Fabrication Routes

- Spray Pyrolysis: This technique uses a hot substrate to sinter active elements in precursor solution, usually gives best Figure of Merit in FTO coatings. Substrate temperature, precursor solution content, droplet sizes, atomizing gas pressure, solution flow rate are parameters of optimization.
- Sol-gel coating: the chemical process where a colloidal suspension of small particles are used to form a gel (network) of desired composition. Parameters include pH of the sol, type of solvent, source materials, deposition method and annealing temperature.