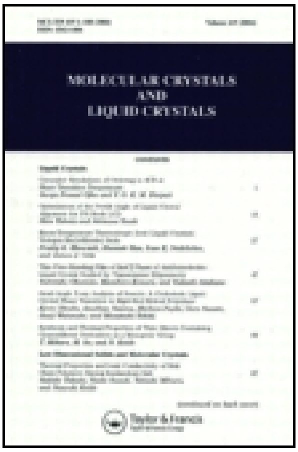

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Large Threshold Voltage Shifts of Nanostructured-Thin Film ZnS:Mn Electroluminescent Devices

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We have studied electro-optical properties of nanostructured-thin film electroluminescent devices(NS-TFELD) with a nanosized-tantalum pentoxide(Ta_2O_5) insulator layer inserted into the ZnS:Mn phosphor layer. A large threshold voltage shift ΔV_{th} has been observed in NS-TFELD. The change in the transferred charge $\triangle Q$ seems to relate to the large shifts of ΔV_{th}, implying that the change in interface states due to the nanosized oxide layer will be responsible for the shifts of V_{th}.

Keywords: ZnS:Mn electroluminescent device; Nanosized-Ta_2O_5 insulator; Threshold voltage shift; Interface states

Introduction

Luminescence properties of nanostructured-semiconductors with nanometer-size multilayers or nanocrystals have become of great interest since they exhibit characteristics being different form bulk semiconductors due to the quantum confinement effects and much effort is now being spent on studying the activator ion doped-semiconductor nanocrystals and developing the nanostructured-thin film electroluminescent devices (NS-TFELD).[1,2,3] Many workers have been already reported about the effects of quantum confinement on photoluminescence of NS-ZnS doped with Mn,[4,5] Cu,[6,7] and Eu,[7] while some research groups have observed the electroluminescence from NS-ZnS:Cu.[8,9] The NS-TFELD show interesting characteristics being different from the conventional TFELD such as the red shift of the emission peak and a band-gap widening due to the decrease in the lattice constant and the quantum confinement effects.[9] In NS-TFELD, another peculiar behavior of the enormous decrease in the threshold voltage V_{th} has been reported.[10]

In this work, we fabricated NS-TFELD with a ZnS:Mn phosphor layer devided by a nanosized-Ta_2O_5 insulating layer and investigated the dependency of V_{th} on the thickness of the insulating layer. In addition, an explanation for the shift of V_{th} is given, based on the tunneling mechanism of electrons from the phosphor-insulator interfaces.[11]

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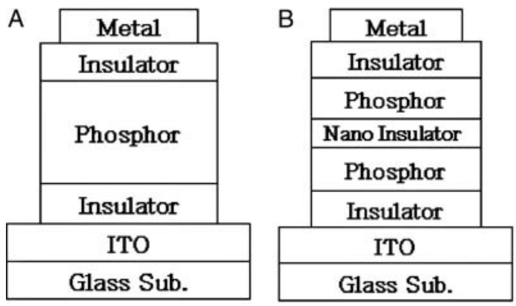

Figure 1. Schematic illustration of conventional TFELD (a) and NS-TFELD with a phosphor layer devided by a nanosized-insulating layer (b).

Experimental

Conventional TFELD prepared for this work consist of a glass substrate / indium tin oxide (150 nm thickness)/Ta_2O_5 insulating layer(300 nm) /ZnS:Mn phosphor layer(400 nm)/Ta_2O_5 insulating layer (300 nm)/metal (Pt) electrode, as illustrated in Fig. 1. Compared to the conventional TFELD, NS-TFELD has a unique emission layer structure with an Ta_2O_5 insulator layer inserted into the phosphor layer. ZnS:Mn phosphor layer was deposited by a rf magnetron sputtering at Ar pressure of 10mTorr and rf power density of 3.5 W/cm^2 on the substrate heated up to 200°C. ZnS powder mixed with Mn metal (1mol%) was used as the target source. Ta_2O_5 insulator is known to be one of promising materials showing almost perfect optoelectric characteristics for TFELD.[12] This is why we select it as the insulating layer. All insulating layers were deposited by a rf reactive magnetron sputtering using Ta_2O_5 target in the atmosphere of Ar and O_2 mixture (90:10) gases at the room temperature with biasing rf power of 4.38 W/cm^2. The thickness of nano-sized insulators were controlled by the biasing time of rf power. The back Pt electrode was prepared by a dc-sputtering method in pure Ar atmosphere.

Nanosized-Ta_2O_5 layer was confirmed by SEM(Hitach S-4200) and X-ray reflectivity(XRR, PANalytical X'Pert-MRD) measurement. Luminance–voltage (L-V) characteristics were measured by a Chromameter(Minolta CS100) under bias of 1KHz sine wave while the transferred charge-voltage(ΔQ-V) was analyzed by using the Sawyer-Tower circuit and a digitizing oscilloscope(Tektronix DPO4034).

Results and Discussion

Figure 2 shows a cross-sectional SEM image of NS-TFELD. As seen in Fig. 2, the phosphor layer is grown between two insulating layers even if we cannot confirm the nanosized-insulating layer inside it because of too small thickness. Figure 3 represents the XRR data of NS-TFELD. As plotted in Fig. 3, one can confirm that nanosized-Ta_2O_5 insulator with thickness of 5∼20nm was grown between the ZnS:Mn phosphor layers. The thickness of nanosized-Ta_2O_5 insulating layers was estimated by 6∼22nm from the XRR data.

In Fig. 4, the L-V characteristics of the conventional TFELD(denoted by 0 nm) and NS-TFELD are plotted. It is found that increasing in thickness of nanosized-insulator results in a large decrease in the threshold voltages V_{th} (up to 22.5%) in addition to an increase in of the luminance. As illustrated in Fig. 5, which is a data rearranged from Fig. 4, the

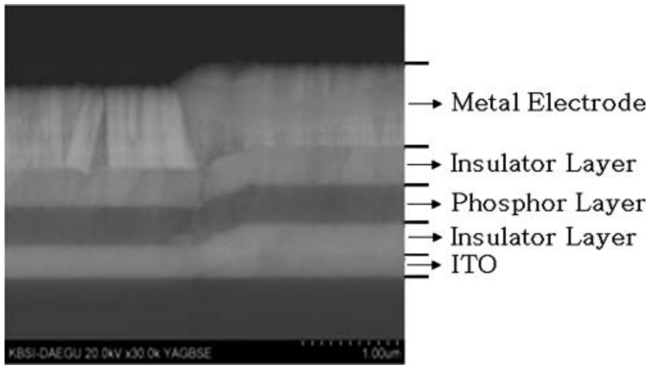

Figure 2. SEM image of cross-sectional view of NS-TFELD.

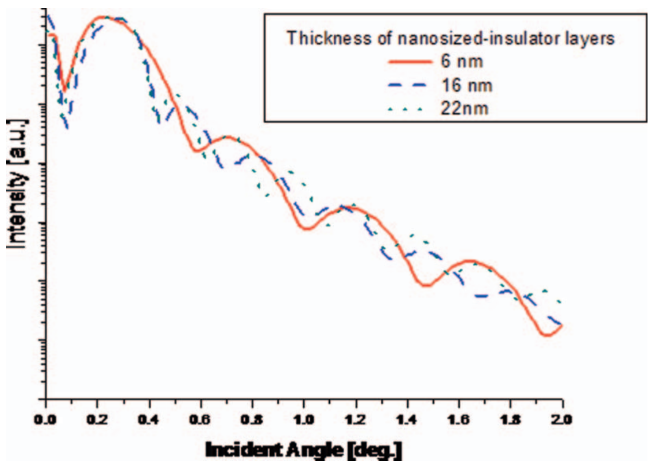

Figure 3. XRR data of nanosized-Ta_2O_5 thin film on glass substrate.

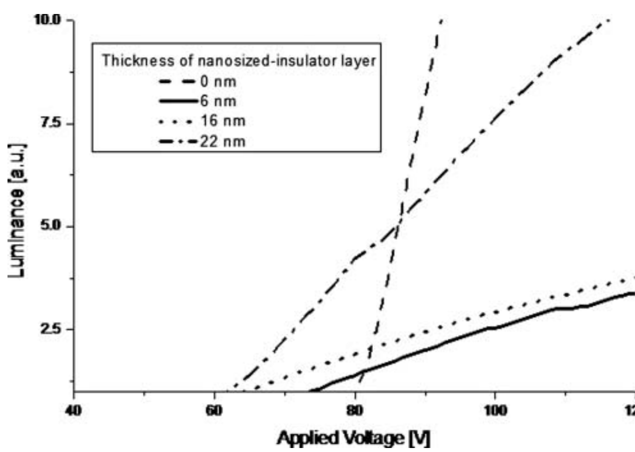

Figure 4. Luminance vs. voltage characteristics(L-V) of conventional TFELD (0nm) and NS-TFELD (6∼22nm).

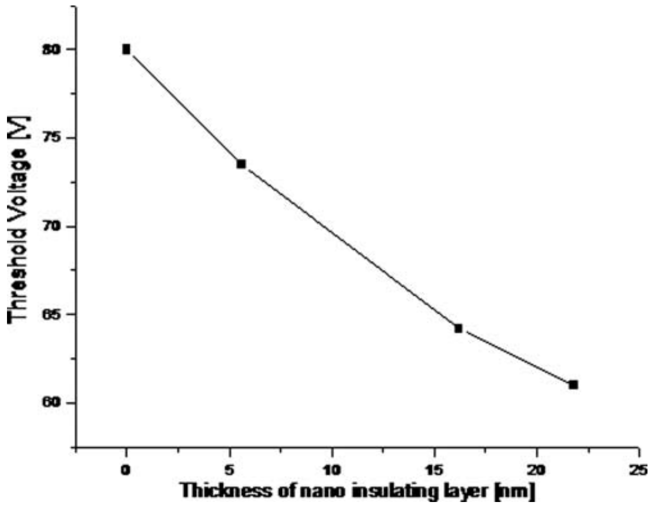

Figure 5. Threshold voltage shift vs. thickness of the nanosized-insulating layer.

threshold voltages decreased from 80V to 75V, 65V and 60V with increasing thickness of nanosized-insulators from 0nm to 6nm, 16nm and 22nm, respectively.

Figure 6 is a plot of the transferred charge △Q as a function of applied voltages V(△Q-V) in order to elucidate the reason for the large shift V_{th}. As revealed in Fig. 6, △Q values increased with increasing thickness of the nanosized-insulator. △Q is known to be proportional to the pure electron tunneling rate from the Dirac quantum well and depends strongly on the interface states between the phosphor layer and the insulator layer.[11] It should be kept in mind that NS-TFELD has two additional interfaces by inserting the nanosized-insulating layer into the phosphor layer. Therefore, one can expect more

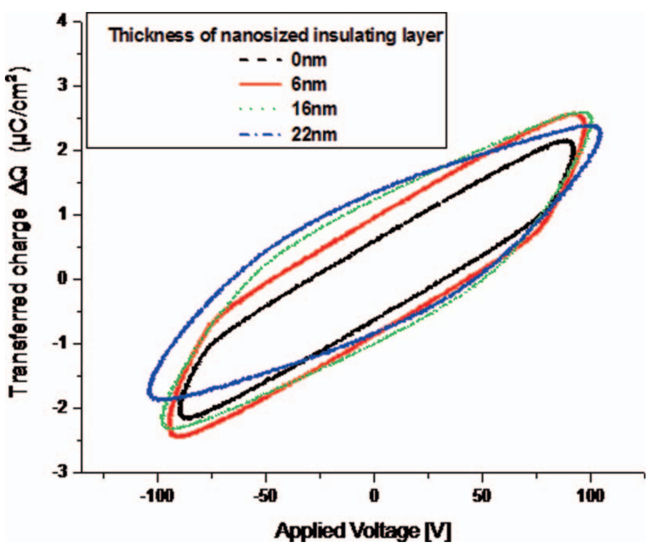

Figure 6. Transferred Charge vs. applied voltages (△Q-V) characteristic diagram.

interface states to emit carriers, yielding larger △Q. △Q-V data suggests strongly that the large shifts seen in NS-TFELD originate from the large change in △Q, due to a change in the interface states such as the interface state density and the pure tunneling rate from the Dirac quantum well.

Conclusions

The nanostructured-thin film ZnS:Mn electroluminescent device with a nanosized- insulator layer inserted into the phosphor revealed a large threshold voltage shift up to 22.5%. The large shifts of the threshold voltages seen in the nanostructured-devices have a deep relation to an increase in the transferred charge, namely, the increase in the carriers emitted from the two additional interfaces. The change in the interface states between the phosphor and the inserted nanosized-insulator may be responsible for the large shifts of the threshold voltages. Nanosized-insulating layer helps us to develop TFELD operating at a very low drive voltage.

Acknowledgment

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