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Barrier Layers and Pulsed Laser Annealing Effects on TFEL Device with Cu and Ag co-doped SrS blue Phosphor Layer

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Abstract

In order to enhance performance, stability, and brightness of inorganic blue-light emitting EL device, barrier layer structure and pulsed laser annealing(PLA) treatment were introduced. The barrier layer structure was utilized for improving brightness of the device and instead of thermal annealing, pulsed laser annealing process was used. From this study, optimum barrier layer thickness and number of pulsed laser irradiation are established.

1. Introduction

Although inorganic TFEL display devices have various advantages such as simple fabrication process, wide view angle, full solid state, fast response time, and others, full colour TFEL display devices have been delayed due to mainly lack of suitable blue phosphor materials.

After Sun's work[1], SrS:Cu,Ag phosphor material has been known for a new strong candidate blue phosphor material to realize full colour EL displays devices. However, unlike ZnS-based phosphor materials, understanding the mechanism of SrS-based phosphor is very limited.

From several previous reports[2,3,4,5], barrier layer structure and pulsed laser annealing treatment can offer improvements in terms of brightness(i.e., luminance) and stability of EL devices. The positive effect of the barrier layer structure on brightness and efficiency in TFEL device with ZnS:Mn phosphor layers was shown by Cranton, W. M.[2]. Instead of high temperature thermal annealing, relatively simple pulsed laser annealing process was already applied for increasing brightness and stability of ZnS-based TFEL devices and then pulsed laser annealed TFEL devices showed better performance than thermal annealed devices[5].

In this study, we have combined the barrier layer structure and pulsed laser annealing treatment for enhancing performance of inorganic TFEL devices with Cu and Ag co-doped alkaline-earth sulfide(SrS:Cu,Ag) phosphor layer. The main objectives are to investigate barrier layers (Y_2O_3) and pulsed laser annealing effects on the TFEL devices and establish optimum parameters such as barrier layer thickness, number of pulsed laser irradiation, and laser fluence(i.e., laser energy density).

2. Experimental

2.1 TFEL Device

The TFEL devices prepared for this study have the same sandwich structure with bottom and top insulating layers as the standard EL devices. However, the barrier layers were grown in the middle of the phosphor layer with various thickness from 10 nm up to 30 nm including non-barrier layer device on the same ITO glass substrate. Yttrium oxide thin films were applied for both insulating layers and barrier layers. For the phosphor layer, Cu and Ag co-doped SrS(SrS:Cu,Ag) thin films are deposited. The insulating, barrier, and phosphor layers were deposited by rf magnetron sputtering technique. The cross-sectional diagram and the top view of the fabricated test devices is shown in Figure 1(b).

As deposition parameters, base and working(i.e., plasma or sputtering) pressures of a vacuum chamber were of 1×10^{-6} Torr and 15 mTorr, respectively. Argon(Ar) was used as sputtering gas and the glass substrate temperature for yttrium oxide dielectric layers including barrier layers was set at 190 °C. These parameters including the substrate temperature were optimized in our research group[6]. The thickness of the top and bottom yttrium oxide insulating layer was 200 nm. The thickness of each layer of the devices is monitored by using 650 nm wavelength laser beam as in-situ interferometric technique.

For the blue phosphor layer, SrS:Cu,Ag(Cu 0.4 at.% and Ag 0.6 at.%) thin films were deposited at 3 mTorr working pressure and 200 °C substrate temperature under Ar atmosphere. The thickness of the bottom phosphor layer was approximately 250 nm.

So total effective phosphor layer had the thickness of 500 nm.

The test TFEL devices were completed by depositing circular Al electrodes on the top using thermal evaporation.

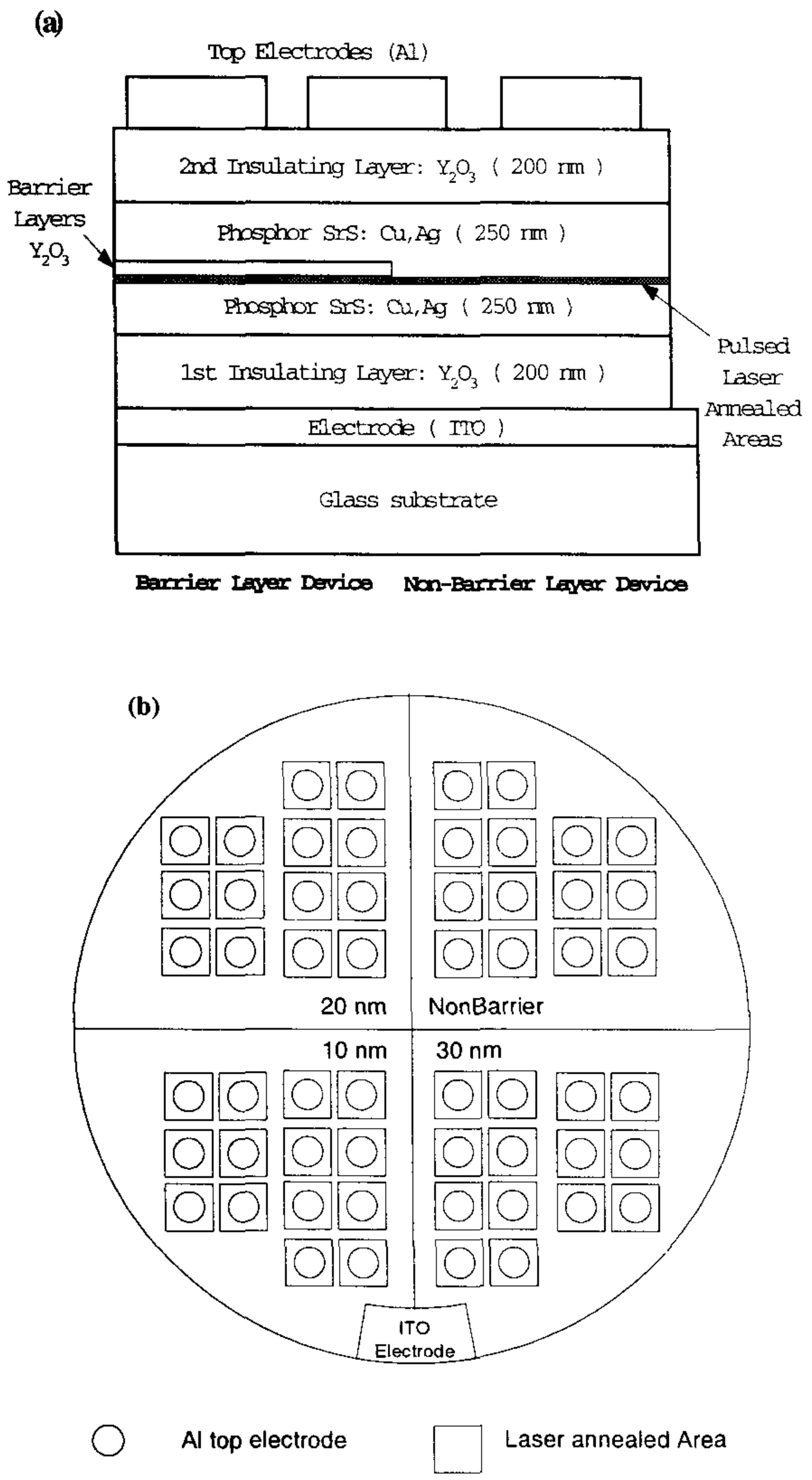

Figure 1. Inorganic ACTFEL Devices: (a) Cross-sectional diagram, and (b) top view of fabricated TFEL cells with laser annealed area.

2.2 Pulsed laser annealing

After deposition of the bottom phosphor layer, the phosphor layer was subjected to a pulsed-laser annealing treatment under pressure of 150 psi in Ar environment. For laser annealing process, a 248 nm (= 5 eV) KrF excimer laser system(Lambda Physik) was used. Two different laser fluences (average 1.8 and 2.2J/cm^2) were applied. In addition, various numbers of laser irradiation were utilised. With the higher laser fluence, the number of laser pulses varied from 2 to 5 pulses, while at low laser fluence, it has the range of 4 up to 7 pulses. The laser annealing treatment was applied to each quarter of the bottom phosphor layer only. The laser annealed spot size was 5 x 5 mm square shape. The laser annealed areas on the devices are shown in Figure 1 (b).

3. Results

3.1 Laser annealing effects on non-barrier devices

EL emission spectra of non-barrier layer(NBL) devices were affected by pure laser annealing treatment so that they can provide meaningful information to understand pulsed laser annealing effect. There are three emission bands observed at 503, 532, and 556 nm, respectively. In terms of emission intensity, the device of low laser fluence showed better characteristics than that of high laser fluence. Under the low laser fluence, the EL device that had 4-pulse laser irradiation showed the highest emission intensity. The intensity decreased as the number of pulses increased. Figure 2 shows EL spectra of non-barrier layer EL devices in low laser fluence with various laser irradiations. While under high laser fluence, there was minor irregularity, but a similar trend of intensity could be identified.

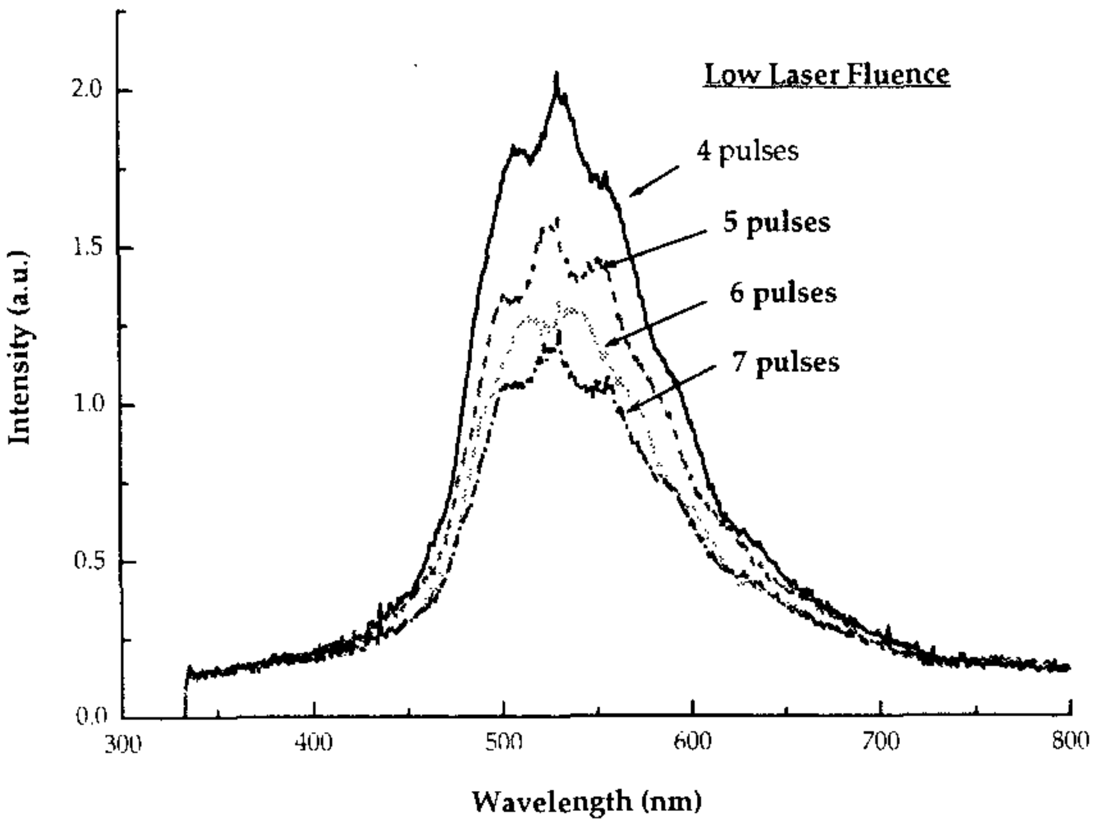

Figure 2. EL spectrum of non-barrier layer devices with laser annealing treatment in the lower laser fluence

In order to obtain more detailed characteristics of electroluminescence(EL) of non-barrier layer devices, EL emission properties of only 4 and 5 pulse laser annealed NBL devices are presented in Figure 3. From this figure, we can observe a clear trend in pulsed laser annealing dependence. In low fluence, the intensity of the non barrier layer device with 4 pulse laser annealing treatment was almost twice as high as the devices with the same number of laser pulses under high fluence. As a result, fewer pulses with low laser fluence is clearly more effective.

From Figure 1 to Figure 3, there are some vibrations in EL spectra. These vibrations(i.e., noises) are due to interference by the multiple stacked thin film structure[7].

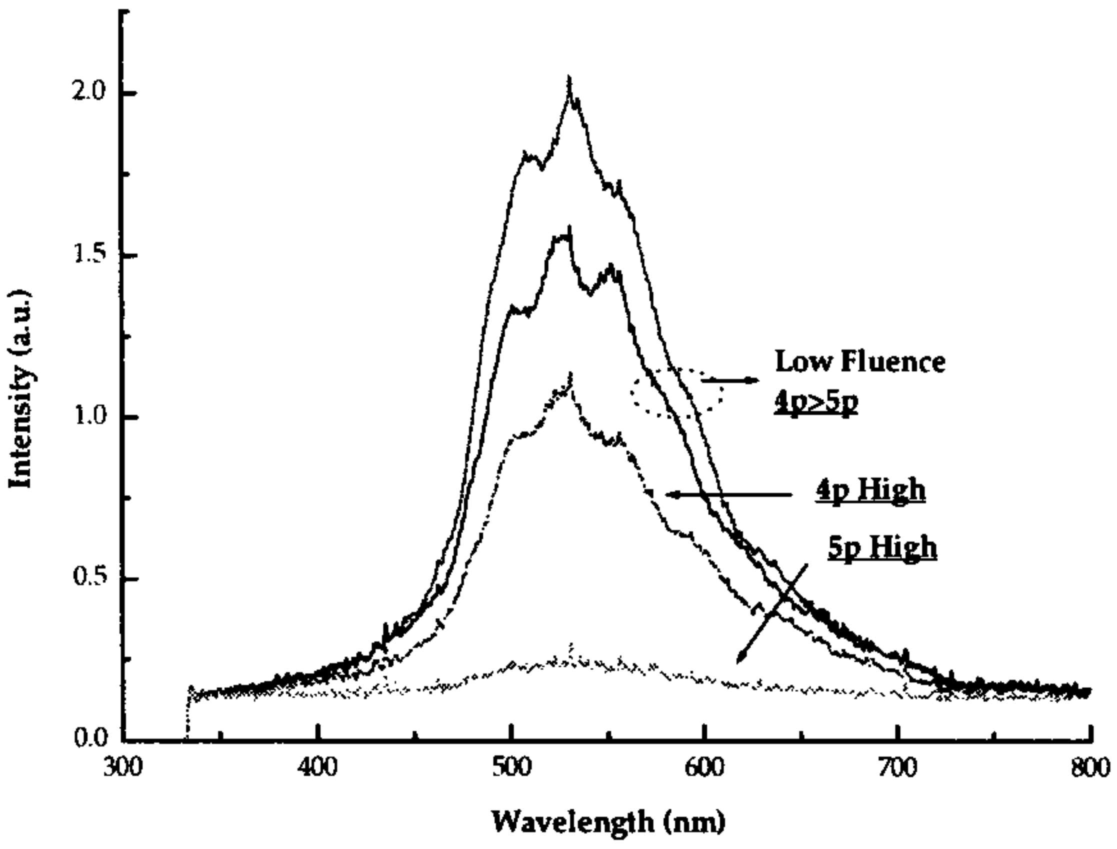

Figure 3. EL spectrum of NBL EL devices with 4 and 5 pulse laser annealing in low and high fluence, respectively.

3.2 Barrier layer thickness effects in EL

At 2 and 4 pulses with high and low fluence, respectively, there was no significant effect associated with the addition of the barrier layer. On the contrary, the non-barrier layer devices showed better results. Even though its increase in EL intensity was not significant under high fluence conditions. However, individual devices with different laser irradiation showed improvement due to the barrier layer insertion. As a tentative analysis, they might not be improved, but the non-barrier layer devices were degraded by high number of pulse with high fluence.

In lower fluence, the devices with 10 (5, 6, and 7 pulses) or 30 nm (6 and 7 pulses) barrier layer thickness had significant improvement compared to the non-barrier layer devices with the same parameters. In particular, EL intensity greatly depended on the only 10 nm barrier layer thickness. For 10 nm barrier layer, EL emission intensity showed up to a 60 % increase in 5-time laser irradiated NBL device only. Compared with NBL device with the 4-time laser irradiated, it showed at least a 39 % increase in its intensity, while other devices with different barrier thickness and laser irradiation had only around 10 % increase. The barrier layer thickness dependence is in agreement with the result from thermal annealed 10 nm single barrier layer devices with ZnS:Mn phosphor layers[2].

3.3 Laser fluence and irradiation

In addition to spectral measurements, brightness-voltage(*B-V*) characteristics were studied to examine the effect of laser annealing on EL performance. According to the *B-V* curves of barrier layer devices, the results can be divided in to two subgroups: 10/20 nm barrier layers and 30 nm barrier layers. Figure 4 and Figure 5 show 20 nm barrier layer device(high fluence) and 30 nm barrier layer device (low fluence), respectively. Like the NBL devices, the brightness of 10 and 20 nm barrier layer devices decreases with the number of laser annealing pulses. Although there were minor irregularities in 10 and 20 nm barrier layers, the highest brightness was on the lower pulse laser annealed devices. The typical trend of brightness decreasing is shown in Figure 4.

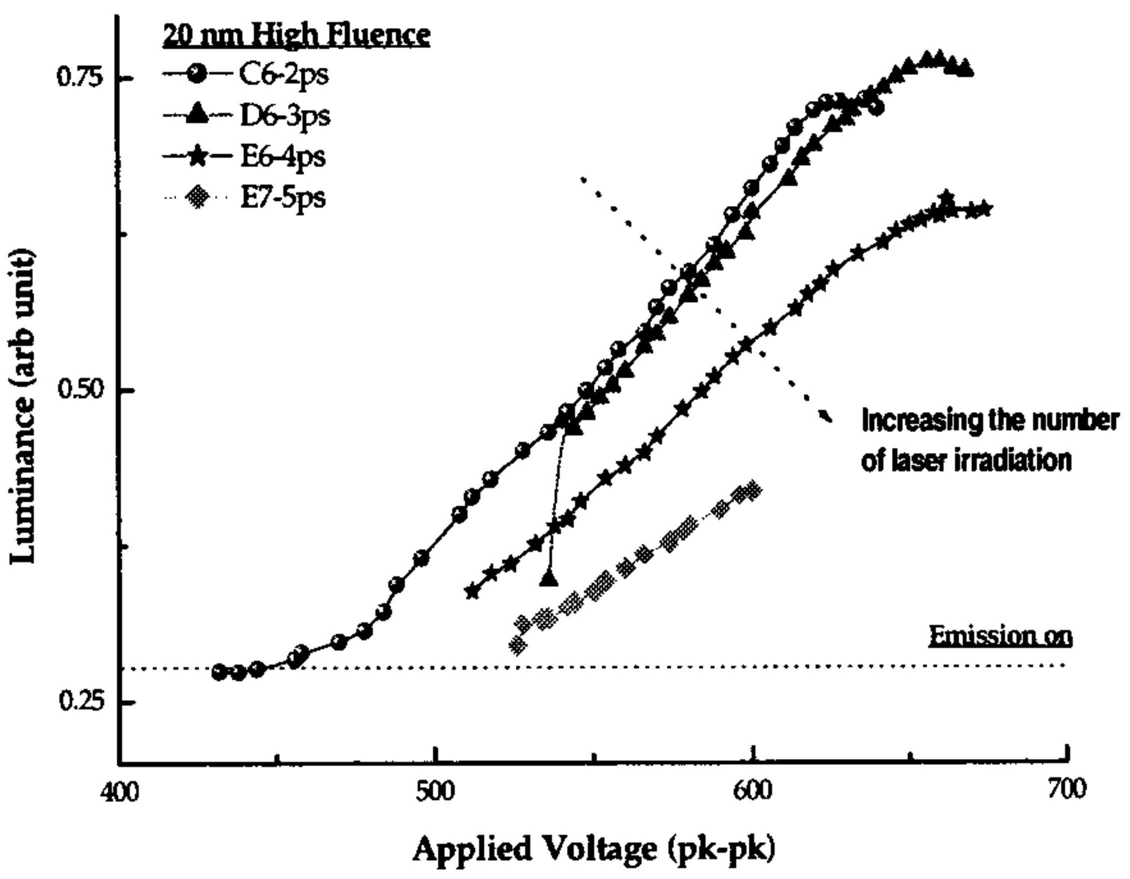

Figure 4. *B-V* properties of 20 nm barrier layer devices in high laser fluence

For 30 nm barrier layer devices, unlike NBL, 10nm and 20 nm barrier layer devices, there was an exception in the *B-V* trend. The brightness was improved with the numbers of the laser pulse in low and high fluence. Seven-time laser irradiated device with the lower fluence had the highest intensity among 30 nm barrier layer devices. The intensity in high fluence was almost saturated in 4 or 5 pulses. This needs more investigation to determine the reasons for the discrepancy. However, the more important thing is that the lower laser fluence still provides the highest brightness.

The barrier layer and laser annealing effects discussed above are incorporated in Figure 6. These devices showed relatively good performing *B-V* characteristics among all fabricated devices in EL emission properties. The devices that were annealed by low fluence are better than ones in high fluences in brightness and driving voltage.

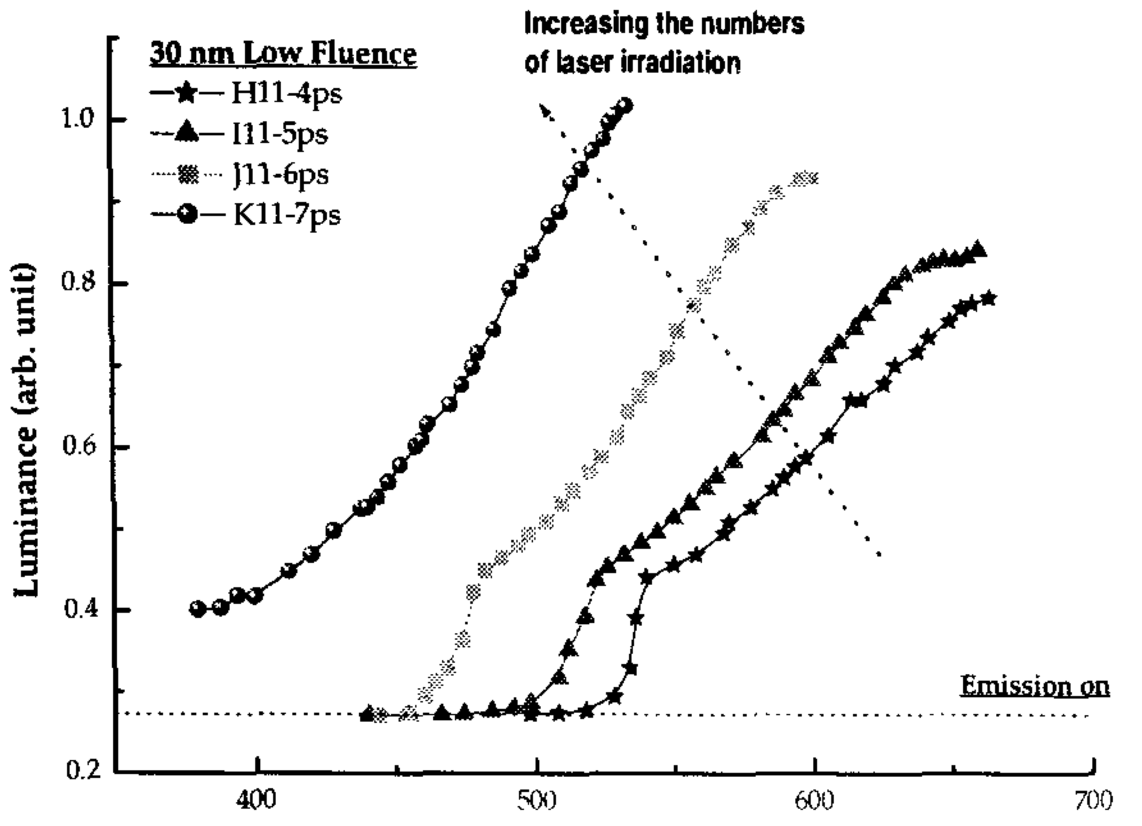

Figure 5. ***B-V*** **properties of 30 nm barrier layer device in low laser fluence**

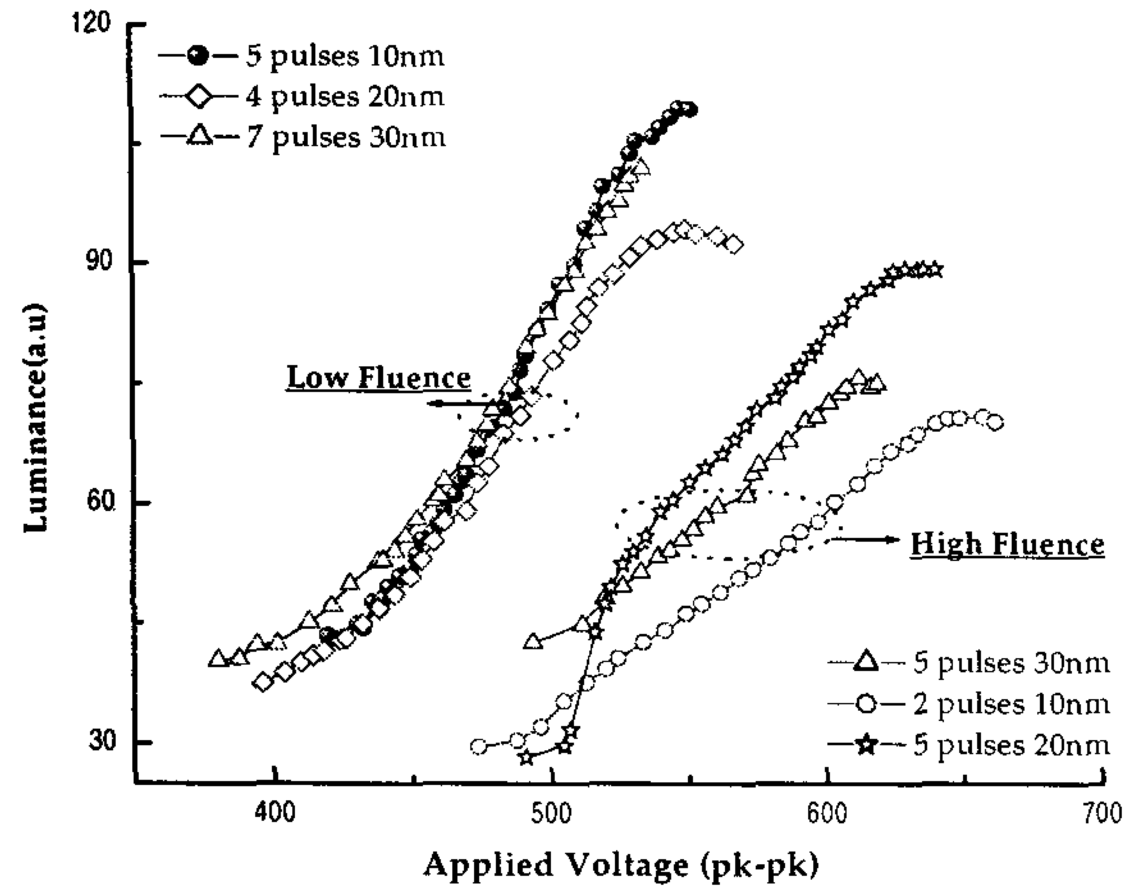

Figure 6. ***B-V*** **properties of laser annealed devices with barrier layers among the best EL performance**

4. Conclusions

With the barrier layer structure, the devices showed high correlation with the barrier layer thickness. From the experiment, 10 nm thickness of the barrier layer(see Fig. 6) was the optimum condition to enhance SrS:Cu,Ag blue EL emission intensity and device stability.

For pulsed laser annealing effects, we established the optimum parameters for laser energy density(fluence) and the numbers of laser irradiation; on average, 1.8 J/cm^2 and 5-time laser pulse, respectively.

Regarding the lower laser fluence dependence, it might be predicted that the higher laser fluence and irradiation can cause degradation of the bottom phosphor layer due to laser ablation. In other words, after the annealing, the phosphor layer started to get into multiple re-growing regimes[8] so that in low fluence, crystallinity of the phosphor layer can be improved due to having fine grain layer.

In laser irradiation, the lower numbers of the laser pulse can be considered one of the critical factors which are affecting EL emission properties. With the laser irradiation, the insulator-semiconductor interface states as a major carrier injection source could be favourable or detrimental.

In device structure and material engineering, a combination of the barrier layer and pulsed laser annealing(PLA) was introduced. We can confirm that the barrier layers and pulsed laser annealing in alkaline-earth sulfides have feasibility to improve EL characteristics. As it is mentioned earlier, particularly, the device performance depended strongly on the barrier layer thickness and laser fluence. For laser annealing, low laser fluence and low numbers of laser irradiation are effective in improving the device performance whether the device has the barrier layers or not.

Further investigation is to be carried out with lower laser fluence and fewer pulses. In addition, the dielectric and ferroelectric materials used as the barrier layers will be investigated further.

5. References

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