

## Y<sub>2</sub>O<sub>3</sub> Red Phosphors for General Lighting coated by Atomic Layer Deposition (ALD) of ZnO for Enhanced Efficacy, Lifetime, and Thermal Stability

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Trichromatic RGB mixtures of phosphors for white light, either for cathodoluminescent (CL) applications such as BLU or ESL, or for photoluminescent (PL) applications, such as compact fluorescent (CFL) or near-UV LED, typically use a red component of Y<sub>2</sub>O<sub>3</sub>:Eu or Y<sub>2</sub>O<sub>3</sub>S:Eu, depending on the degree of saturation desired. Although these compounds represent the best red phosphors available, they suffer from diminishing efficacy and lifetime with increasing power density, as seen in Fig. 1. The severe loss in efficacy is resultant of the poor thermal and electrical conductivity (in CL use) of Y<sub>2</sub>O<sub>3</sub>:Eu particles. The situation is worsened in that most white-light applications need to be operated at power densities exceeding 150mW/cm<sup>2</sup>.<sup>1</sup> Furthermore, phosphor screens often employ silicate binders for adherence to the glass lamp, further diminishing thermal conductivity. Some investigations have attempted to mitigate this by coating the phosphors with CNT, however, the black nanotubes are non-luminescent and results are insufficient at higher power densities.<sup>2</sup> CNT, being hydrophobic, also complicates the deposition process. We present here a first demonstration of coating of Y<sub>2</sub>O<sub>3</sub>:Eu red phosphor powder with ALD ZnO. ALD provides unique features such as precise thickness control of ZnO thin films with atomic resolution, high uniformity and absolute conformity. ALD is capable of coating complex surface morphologies capable to penetrate minute voids. A thin layer of red phosphor powder was deposited on a Si substrate by sedimentation technique and coated with a thin film of ALD ZnO. The ALD ZnO coatings were deposited using diethyl Zinc and H<sub>2</sub>O vapor at 150°C. The film deposition rate was 2Å/cycle.<sup>3</sup> Figure 2(a) is an SEM image of loosely packed red phosphor particles and Fig. 2(b) shows that every single red phosphor particle was coated with 100 nm ZnO including the Si substrate. Figure 3 shows the electrical conductivity of the ALD ZnO films. After coating the red phosphor, the four-point probe measurements revealed very low resistivity (~0.02Ω-cm) for the as-deposited 100nm ALD ZnO thin films. The photoluminescence study revealed a bright red emission of Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup>. After coating with ALD ZnO, our measurements show that the red emission of Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup> is conserved, as shown in Fig.4. The results demonstrate that not only can the silicate binder be replaced with luminescent ZnO, but thermal and electrical conductivity can be enhanced, in order to improve efficacy, lifetime, and thermal stability, by the same process.

### References:

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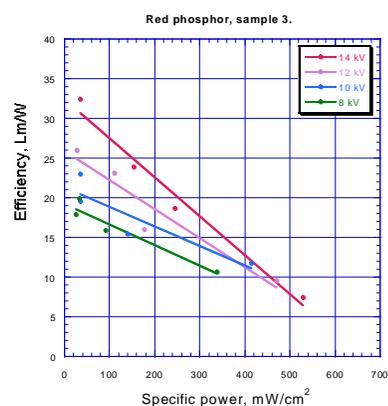


Figure 1. Typical efficacy vs Power Density Plot of Y<sub>2</sub>O<sub>3</sub>:Eu red phosphor<sup>1</sup>.

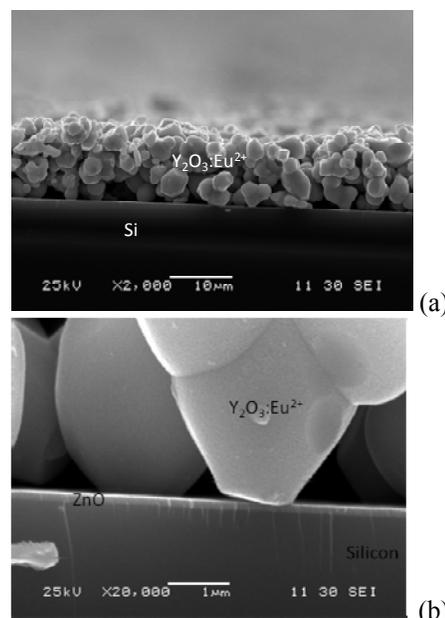


Figure 2. SEM image of (a) loosely packed Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup> particles deposited by sedimentation and (b) higher magnification of Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup> particles coated with 100 nm of ALD ZnO film.

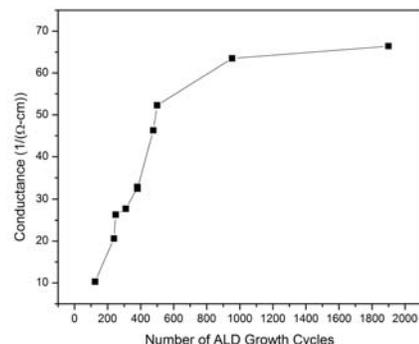


Figure 3. Conductance of ALD ZnO vs ALD cycle. ZnO conductivity increases as the coating thickness is increased.



Figure 4. Photoluminescence Study of Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup> and Y<sub>2</sub>O<sub>3</sub>:Eu<sup>2+</sup> coated with ZnO.