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Extraction of High Luminescence Light from Light Emitting Devices Using ZnS QDs Material

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Abstract : Extraction of efficient light from the light-emitting device in an economical way is always challenging. Modern technology demands more and more performances of devices fabricated at low cost. In this paper, we have demonstrated the synthesis of Zinc Sulfide Quantum Dots (ZnS QDs) by a facile and cost-effective solvothermal method, and their performance of light extraction as a light-emitting device is investigated extensively. Further, the ZnS QDs are characterized by modern tools like XRD, SEM, and EDAX spectroscopy respectively. The light extraction performance of ZnS QDs thin film is more questing which can be recommended for mass production and industrial applications.

Keywords: Zinc Sulfide, Quantum Dots, Solvothermal method, Thin film, and Light Extraction

1. Introduction

Zinc sulfide (ZnS) is the most exceptional wide direct bandgap semiconducting material having attractive physical, chemical, electronic, and optical properties which are significantly different when the bulk ZnS reduces to ZnS nanostructure. [1–3] The ZnS material exists in two different polymorphic phases; cubic zinc blende (ZB) and hexagonal wurtzite (WZ). [4] So, various synthesis methods have been investigated for the growth of diverse ZnS nanostructures, such as nanoparticles, nanorods, nanobelts, nanowires, and nanosheets respectively. [5–7] Similarly, ZnS nanostructures have been maneuvered for diverse applications in flat-panel displays, [8] electroluminescent devices (ELDs), [9] sensors, [10] lasers, [11] photocatalysis, [12] and infrared(IR) windows [13] etc. Still, there is a lot of scope for the development of a pristine and novel nanostructure of ZnS in a cost-effective way, and these materials scientists are searching for new techniques.

Over the past 30 years, research has been centered on light emitting devices (LEDs) as next-generation light sources and display devices because of their quick response times, adaptability, and affordable processing. [14,15] The low out-coupling efficiency still remains the biggest challenge in these devices. About 30% of light is trapped at the substrate-air interface which is reducing the performance of devices. [16] The performance of the devices can be enhanced by manifolds by choosing suitable light-emitting nanomaterials having exciting morphology. [17] The Polymer-nanoparticle combination is one of the finest ways to accomplish the performance of the devices. Polymer helps to nucleate the nanoparticle and produce novel nanomaterials and morphology. [18] Sanjeev *et al.* reported the use of a polystyrene-Al_2O_3 combination and demonstrated a 40% increase in the light extraction efficiency of a green OLED. [19] Similarly, Sexana et al. explored the improvements in light out-coupling techniques, by utilizing substrate modification methods, micro-lens arrays, micro-cavity effect, photonic crystals, and surface plasmon-enhanced techniques. [20]

To the best of our knowledge, Polydimethylsiloxane (PDMS)-ZnS combination has not been investigated as an external light extraction layer in LEDs despite of its high functional advantages. In this work, we have focused on the facile synthesis and growth of ZnS QDs, and their light extraction performance over the Fluorine-doped Tin Oxide (FTO) is explored in the scientific world. The light extraction performance of 20 mg ZnS QDs thin film placed over the FTO is higher which is more interesting.

2. Experimental Sections

*2.1 **Material Synthesis***

The synthesis of Zinc Sulphide has been executed by the simple, easy and cost-effective solvothermal method taking Zinc Acetate and Sodium Sulphide as main precursors. In the beginning, an amount of 0.0167 gm of Zinc Acetate was dissolved in 140 ml of ethanol in a beaker then 1 µl of PDMS was added to the Zinc Acetate solution. After complete dissolution of the precursors, 0.0167 gm of Sodium Sulphide dissolved in 140 ml of ethanol was dropped cast to the rotating Zinc Acetate and PDMS mixture solution. Then, the solution was transferred into an ultrasonic bath chamber for 30 minutes to get the turbid condition inside the solution. The turbid state in the liquid medium is formed by the reaction of Zn^{2+} and S^{2-} ions which is a clear indication of the formation of Zinc Sulphide material. Finally, the as-synthesized solution was centrifuged and dried at room temperature and used for different characterization and experimental purposes.

2.2 Material Characterization

To identify the crystal structure and crystallite size of the as-synthesized Zinc sulfide nanoparticles, an X-ray diffractometer (PROTO AXRD using Cu-K_α radiation, λ=1.54 Å) was executed. The morphology and composition of the as-prepared sample were examined by FESEM (MERLIN compact with GEMINI I electron column, Zeiss Pvt. Ltd, Germany) equipped with energy dispersive X-ray spectroscopy (EDAX). The intensity of light extracted from the synthesized nanoparticle was measured using the LUX meter, LX-101A, HTC, India.

2.3 Experimental setup

Fig. 1 defines the schematic diagram of the light extraction experiment of the ZnS QDs layer executed by spin coating and is placed above the COB LED light (4 volts rectangular shape made of silicon carbide). The positive and negative terminal of the COB (chip on board) LED light was connected to the battery eliminator and the separation distance between the Lux meter and the LED light was fixed at 20 cm. The experiment was recorded in fixed intervals of time due to the probability of receiving light in the Lux meter being maximum and could record more intense extracted light in an effective manner. First the luminance of the pristine LED (without coating) was measured in a LUX meter then 5 mg, 10 mg and 20 mg of ZnS QDs spin-coated FTOs were recorded eventually.

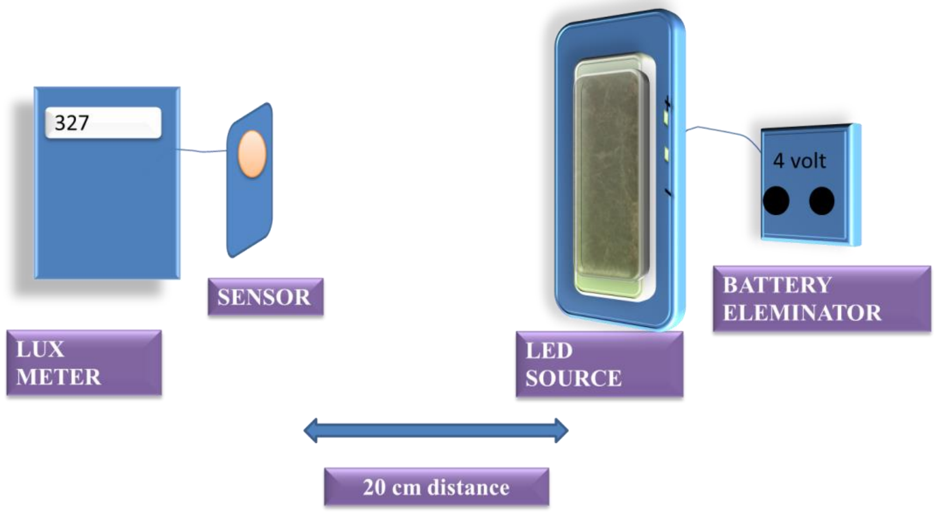

Fig.1 Schematic Diagram of Light Extraction Experiment

3. Result and Discussion

3.1 Characterization of the synthesized ZnS material

The XRD spectrum of the synthesized ZnS material is depicted in Fig. 2 which reveals the pristine nature of the material having a hexagonal crystal structure. The peak positions at (0010),(106),(107),(108),(110), and (1110) are indexed to ZnS material (Reference No#00-012-0688). The observed peaks are distinct and no additional peaks are indexed, clearly specifying the crystallinity and purity of the synthesized nanomaterial. The crystallite size of the synthesized materials is calculated using the formula $d = \frac{k\lambda}{\beta cos\theta}$ and found to be 7 nm. The SEM was executed to recognize the surface morphology of the synthesized nanomaterial.

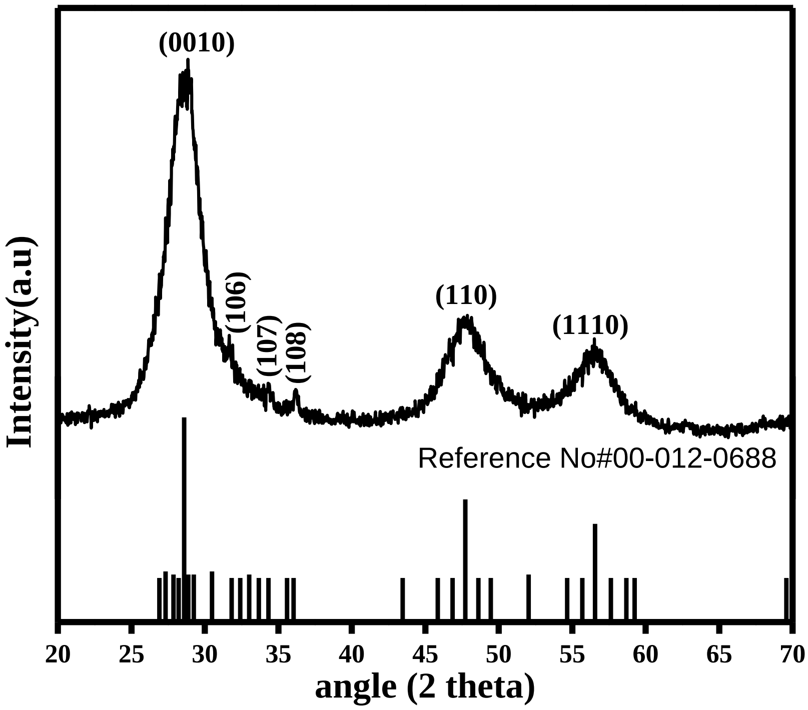

Fig. 2 XRD spectrum of ZnS QDs

Fig. 3 clearly reveals the quantum dots-like structure distributing homogeneously. The size of the quantum dots is calculated as 5-10 nm and the ZnS QDs are agglomerated with each other.

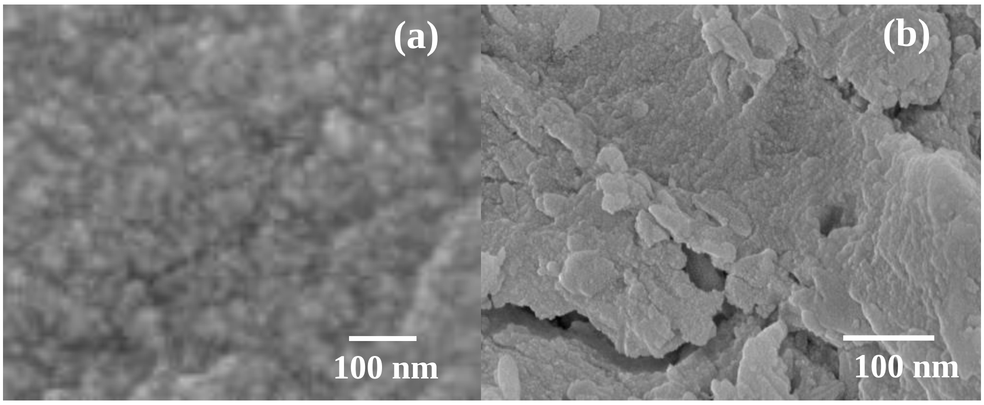

Fig. 3 Low and High magnification image of ZnS QDs

The elementary composition of the synthesized material was identified by the EDAX spectrum and the constituent elements are supplied in Fig. 4. The atomic percentage of Zn is 60.65 and sulfur is 39.39 respectively. The electron mapping of the ZnS QD is executed and its result is supplied in Fig. 4(c) and (d) respectively. The Zn and S elements are present uniformly in the material.

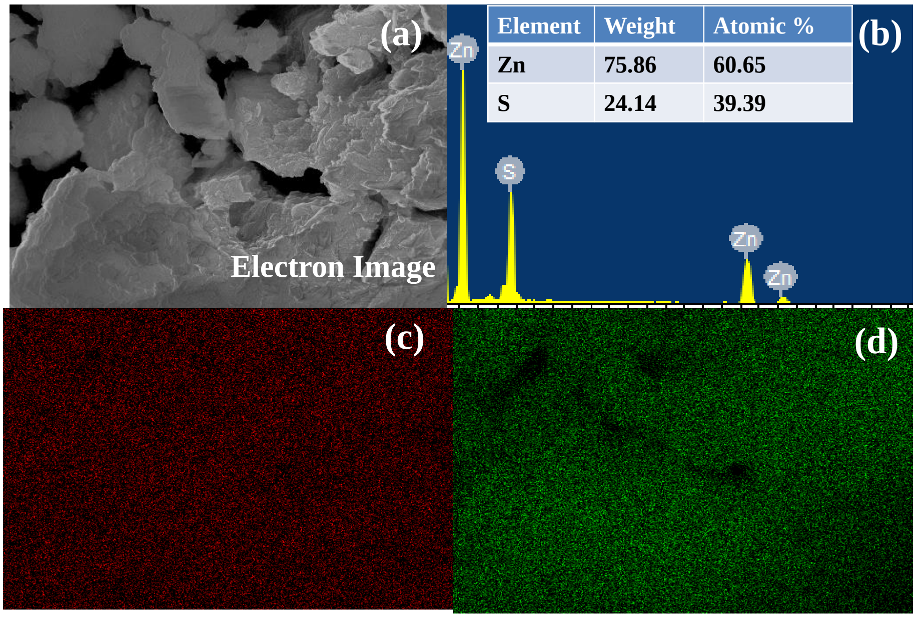

Fig. 4 EDAX and Electron mapping of ZnS QDs

3.2 Light Extraction Performance of ZnS QDs

Fig. 5 represents the light extraction performance of the synthesized ZnS QDs material. It can be clearly observed that the light Illuminance of 20 mg ZnS QDs thin film is higher than the other ZnS QDs thin film due to the participation of more number of ZnS QDs with the photon. The light that emerges from the COB LED light interacts with the ZnS QDs and is extracted from the surface due to electron-photon coupling as a result total internal reflection is minimized and more intensity of light is extracted from the COB LED and is received in the LUX meter. The transparent PDMS polymer and ZnS QDs act as a medium through which light is extracted easily and high intensity of luminescence light is recorded in LUX meter.

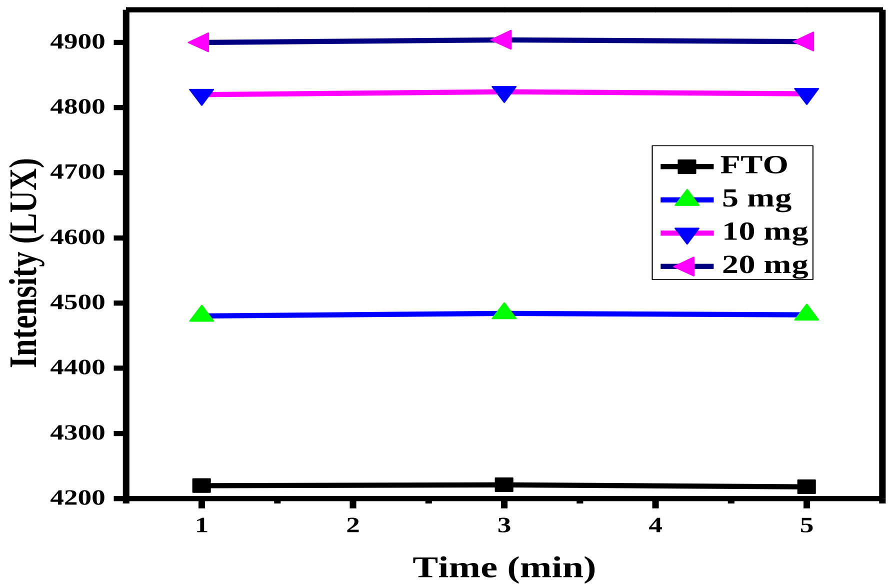

Fig. 5: Light extraction performance of ZnS QDs in different amount of ZnS QDs thin film over COB LED

4. Conclusion

The ZnS QDs are synthesized in an economical solvothermal method which is highly crystalline and pure in nature. The radius of the ZnS quantum dot is calculated to be 5-10 nm. The light extraction performance of ZnS QDs is studied using COB LED and excellent light enhancement is observed. The light enhancement properties of the ZnS QDs may be recommended for industrial application.

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References

[1] S. Ummartyotin and Y. Infahsaeng, *A Comprehensive Review on ZnS: From Synthesis to an Approach on Solar Cell*, Renew. Sustain. Energy Rev. **55**, 17 (2016).

[2] G.-J. Lee and J. J. Wu, *Recent Developments in ZnS Photocatalysts from Synthesis to Photocatalytic Applications—A Review*, Powder Technol. **318**, 8 (2017).

[3] X. Fang, T. Zhai, U. K. Gautam, L. Li, L. Wu, Y. Bando, and D. Golberg, *ZnS Nanostructures: From Synthesis to Applications*, Prog. Mater. Sci. **56**, 175 (2011).

[4] D. R. Vij, *Handbook of Electroluminescent Materials* (CRC press, 2004).

[5] X. Fang, L. Wu, and L. Hu, *ZnS Nanostructure Arrays: A Developing Material Star*, Adv. Mater. **23**, 585 (2011).

[6] D. Moore and Z. L. Wang, *Growth of Anisotropic One-Dimensional ZnS Nanostructures*, J. Mater. Chem. **16**, 3898 (2006).

[7] T. Sinha, D. Lilhare, and A. Khare, *Effects of Various Parameters on Structural and Optical Properties of CBD-Grown ZnS Thin Films: A Review*, J. Electron. Mater. **47**, 1730 (2018).

[8] J. W. Lee, B. Pathangey, M. R. Davidson, P. H. Holloway, E. S. Lambers, A. Davydov, T. J. Anderson, and S. J. Pearton, *Electron Cyclotron Resonance Plasma Etching of Oxides and SrS and ZnS-Based Electroluminescent Materials for Flat Panel Displays*, J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. **16**, 1944 (1998).

[9] H. Yang, P. H. Holloway, and B. B. Ratna, *Photoluminescent and Electroluminescent Properties of Mn-Doped ZnS Nanocrystals*, J. Appl. Phys. **93**, 586 (2003).

[10] X. Fang, Y. Bando, M. Liao, U. K. Gautam, C. Zhi, B. Dierre, B. Liu, T. Zhai, T. Sekiguchi, and Y. Koide, *Single-crystalline ZnS Nanobelts as Ultraviolet-light Sensors*, Adv. Mater. **21**, 2034 (2009).

[11] X. Fang, Y. Bando, U. K. Gautam, T. Zhai, H. Zeng, X. Xu, M. Liao, and D. Golberg, *ZnO and ZnS Nanostructures: Ultraviolet-Light Emitters, Lasers, and Sensors*, Crit. Rev. Solid State Mater. Sci. **34**, 190 (2009).

[12] N. Soltani, E. Saion, M. Z. Hussein, M. Erfani, A. Abedini, G. Bahmanrokh, M. Navasery, and P. Vaziri, *Visible Light-Induced Degradation of Methylene Blue in the Presence of Photocatalytic ZnS and CdS Nanoparticles*, Int. J. Mol. Sci. **13**, 12242 (2012).

[13] Z. Qu, X. Cheng, R. He, Y. Pei, R. Zhang, and D. Fang, *Rapid Heating Thermal Shock Behavior Study of CVD ZnS Infrared Window Material: Numerical and Experimental Study*, J. Alloys Compd. **682**, 565 (2016).

[14] J. Shinar, *Organic Light-Emitting Devices: A Survey* (Springer Science & Business Media, 2004).

[15] S. H. Ko, *Organic Light Emitting Diode: Material, Process and Devices* (BoD–Books on Demand, 2011).

[16] T.-C. Sum and N. Mathews, *Halide Perovskites: Photovoltaics, Light Emitting Devices, and Beyond* (John Wiley & Sons, 2019).

[17] Z. Li, Z. R. Li, and H. Meng, *Organic Light-Emitting Materials and Devices* (CRC press, 2006).

[18] H. Wu, L. Ying, W. Yang, and Y. Cao, *Progress and Perspective of Polymer White Light-Emitting Devices and Materials*, Chem. Soc. Rev. **38**, 3391 (2009).

[19] A. K. Sajeev, N. Agarwal, A. Soman, S. Gupta, M. Katiyar, A. Ajayaghosh, and K. N. N. Unni, *Enhanced Light Extraction from Organic Light Emitting Diodes Using a Flexible Polymer-Nanoparticle Scattering Layer*, Org. Electron. **100**, 106386 (2022).

[20] K. Saxena, V. K. Jain, and D. S. Mehta, *A Review on the Light Extraction Techniques in Organic Electroluminescent Devices*, Opt. Mater. (Amst). **32**, 221 (2009).

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