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SBR Capped ZnS Quantum Dots as Nanoelectronic Filter

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The quantum dots (QD) based filtering circuits work on the principle of capacitive admittance, due to which they have less power dissipation, small dimension, and almost zero noise. In the present study, we report synthesis, characterization, and application of the styrene butadiene rubber (SBR) capped ZnS quantum dots as nanodimensional tuned filter. The ZnS quantum dots are characterized by standard characterization techniques such as absorption spectroscopy, XRD study, and high-resolution TEM microscopy; the admittance variation with frequency is tested for the same. The SBR capped ZnS quantum dots are found to work as a tuned band pass filter with pass band in the range of 20–32 MHz with a critical frequency of 20 MHz.

Схеми фільтрації на основі квантових цяток працюють за принципом ємнісної пропускної здатности, завдяки чому вони мають меншу розсіювану потужність, малі розміри та майже нульовий шум. У цьому дослідженні ми повідомляємо про синтезу, характеризацію та застосування квантових цяток ZnS, покритих стирол-бутадієновим каучуком (СБК), як нанорозмірного налаштованого фільтра. Квантові цятки ZnS характеризуються стандартними методами визначення характеристик, такими як спектроскопія поглинання, дослідження рентґенівської дифракції та просвітна електронна мікроскопія з високою роздільчою здатністю; зміна пропускної здатности з частотою перевіряється на те саме. Встановлено, що квантові цятки ZnS, покриті СБК, працюють як налаштований смуговий фільтер із смугою пропускання в діяпазоні 20–32 МГц із критичною частотою у 20 МГц.

Key words: ZnS, quantum dots, SBR latex, nanofilter, nanotechnology.

Ключові слова: ZnS, квантові цятки, СБК латекс, нанофільтер, нанотехнології.

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1. INTRODUCTION

Electronic filter is the component that allows a specific range of frequencies to pass through it and rejects the other. Depending upon the frequency range, electronic filters are classified as low pass filter (0 Hz to several kHz or MHz), high pass filter (several kHz to several MHz), band pass that allows a band of frequency, band reject filter that rejects a band of frequency. In case of quantum dots, admittance changes with operating frequency. This is the primary characteristic of tuned device and filter. The variation in quantum dot admittance with frequency occurs because quantum dots are associated with capacitance and quantum dot admittance (or impedance) is basically due to capacitance present in the specimen. The capacitance (hence, capacitive admittance) is a function of quantum dot size, shape and material [1].

There are several advantages of using QD based filtering circuits compared to traditional filtering circuits. It works on the principle of QD admittance which is basically capacitive in nature while in general the tuned circuits are made using R and L elements. In QD based filters, power dissipation is very less and producing no considerable noise. Also, as the dimension is very small, simple circuitry, may be used for detecting any signal in a very sophisticated receiver section. The resonance frequency of QD (assembly) is a function of size, shape and material used. Hence, these parameters are fixed for specific QD (assembly) [2].

For disk and spherical shaped quantum dots of radius r, the capacitance is given as follow:

$$C = 8\varepsilon_0(\varepsilon/\varepsilon_0)r \text{ for disk,} \tag{1}$$

$$C = 4\pi\varepsilon_0(\varepsilon/\varepsilon_0)r \text{ for sphere,} \tag{2}$$

where $\varepsilon/\varepsilon_0$ is the dimensionless dielectric constant of the semiconducting material, which forms the dot, and $\varepsilon_0 = 8.8542 \cdot 10^{-12}$ F/m is the dielectric constant of free space. Our quantum dots are of spherical shape, hence, the admittance of our quantum dot variation with size/shape follows the relation (2).

The capping material used for the synthesis is styrene butadiene rubber (SBR) latex, which controls the growth of QD size. The

TABLE 1. Physical properties of styrene butadiene rubber (SBR) latex.

Physical properties of SBR	
Melting point, °C	273
Specific gravity	0.93
Specific heat, J/(gm·K)	1.89
Thermal conductivity, W/(m·K)	1.34
Refractive index	1.53
Dielectric constant	3.1

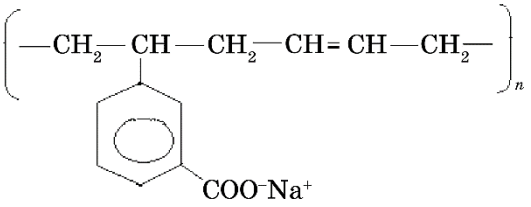

Fig. 1. Structure of styrene butadiene rubber (SBR) latex.

physical properties of SBR and the chemical structure is shown in Table 1 and Fig. 1, respectively [3].

2. EXPERIMENTAL

One coat of SBR latex is drawn over glass substrate and then dried slowly to avoid spilling. The coated glass substrate is dipped into $ZnCl_2$ solution mixed with few drops of HNO_3 for one hour and then taken out followed by ammonia passivation for half an hour. Finally, the glass substrate is dipped into freshly prepared 2 wt.% Na_2S *D/D* water solution, until it appears fully yellow. The milky white thin film contains the semiconductor ZnS quantum dots embedded in SBR latex [4].

The synthesized samples have been tested by UV/VIS spectrophotometer, x-ray diffraction spectrometer, and high-resolution transmission microscope (HRTEM). UV–vis light absorption spectra were obtained using Perkin Elmer Perkin Elmer Lambda 35 ultraviolet visible (UV–vis) spectrophotometer. X-ray diffraction (XRD) patterns were obtained (Bruker AXS, X-ray source: CuK_α) as well as high-resolution transmission electron microscopy (JEM 1000 C XII).

To study the admittance of our synthesized quantum dot samples (assembly of quantum dots), two ends of 99% pure fine gold wire of 0.01 mm diameter are made fixed very close to each other within micron range over the glass substrate. By means of a syringe, a

single tiny drop of quantum dot liquid sample is gently put over the two free ends of gold wires to make the microcontact. The specimen is dried partially by natural process to avoid spilling and then in oven to stick it properly upon the substrate. After that, the free ends of probing wires are connected to admittance (impedance) analyser (Solartron SI 1260). The sample is ready for admittance analysis. Though the quantum dots are embedded in nonconducting matrix (SBR), the electrons (current) can pass through the sample (assembly of quantum dots) by means of tunnelling of electrons from one quantum dot to the another as the quantum dots are isolated from each other by very thin insulating wall of matrix, which is obvious from TEM images of the samples.

3. RESULTS AND DISCUSSION

The absorption spectra of the synthesized ZnS quantum dots are shown in Fig. 2. It can be observed from the figure that a strong absorbance edge occurs at 225 nm for undoped ZnS, determined by drawing a tangent on point, from which there is sudden increase in the absorption (as observed in Fig. 2) to meet the x-axis. From the absorption edge, the nanoband gap of the quantum dot (E_{gn}) is determined from the formula $E_{gn} = hc/\lambda$, where $hc = 1.12$ eV, and λ is the value of absorption edge [5].

In the case of doped samples the absorption spectra are a little 'blue shifted'. The reason for this 'blue-shift' towards lower wavelength is due to increased nucleation rate in the quantum dot crystal on introducing dopant ions into it [6]. This slight blue shift in spectra is also considered an indication of the successful doping of quantum dots. From the absorbance edge, particle size has been estimated by hyperbolic band model [6].

$$R = \sqrt{\frac{2\pi^2 h^2 E_{gb}}{m^*(E_{gn}^2 - E_{gb}^2)}}\,. \tag{3}$$

Here, R is the quantum dot radius to be calculated; whereas, m^* (effective mass of the specimen), h (Planck's constant), E_{gb} (bulk band-gap) are constant for each material. Thus, the size of quantum dots varies with the increase in E_{gn} (the quantum dot band gap), which is determined from the absorption edge in the UV–vis spectrum. The other values used in the present estimation are as follows: bulk band-gap (E_{gb}) for ZnS is of 3.65eV, electron effective mass of ZnS at room temperature is of $3.64 \cdot 10^{-31}$ Kg [7], and the Plank's constant is of $6.626 \cdot 10^{-34}$ J·s. The estimated size of ZnS quantum dots from the 'hyperbolic band model' is of 10.5 nm.

The XRD characteristics of synthesized ZnS quantum dot samples

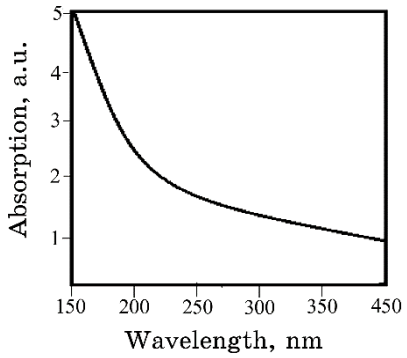

Fig. 2. UV–vis absorption spectra of ZnS quantum dots.

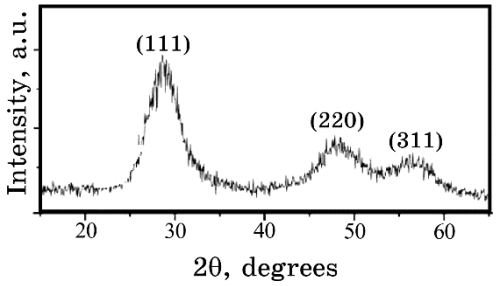

Fig. 3. XRD of ZnS quantum dots.

are shown in Fig. 3. The approximate (average) size of the particle is calculated by using the Debye–Scherrer formula [8]:

$$D = \frac{0.9\lambda}{W \cos\theta}, \tag{2}$$

where λ and θ are the wavelength of x-rays (0.1541 nm) and the glancing angle, respectively. The W and D are full width at half maxima (*FWHM*) and particle diameter (crystallite size), respectively. The crystalline planes corresponding to the first, second, and third XRD peaks are (111), (220), and (311), respectively [9]. The average particle size of the synthesized quantum dots has been estimated to be in the range of 9.61 nm to 11.2 nm from the XRD spectra from the x-ray diffractogram peaks. Further, by comparing the obtained XRD spectra peaks with the International Center Diffraction Data (ICDD) card number JCPDS-00.001.0792, it has been revealed that obtained peaks match that of standard ZnS data. Thus, quantum dots are also having a Wurtzite crystalline structure [10].

Quantum dots' formation and sizes are confirmed by taking high-

resolution transmission electron microscope (HRTEM) images of the prepared samples. It can be observed in Fig. 4 that the size of synthesized ZnS quantum dots is around 10 nm, which is in close agreement with that of the estimated sizes obtained from absorption spectroscopy and XRD.

The admittance *versus* frequency plot for the synthesized SBR capped ZnS quantum dots are shown in Fig. 5. Admittance analysis of ZnS quantum dots capped with SBR is shown in Table 2 to study the changes of admittance with frequency.

It is observed that admittance increases slowly with increase in frequency up to a certain frequency range 2 and after that, at a particular critical frequency, admittance rises in a relatively steeper fashion. This critical frequency of ZnS is of 20 MHz. The admittance remains almost constant in higher frequencies, 32 MHz in present investigation, for ZnS sample in SBR latex.

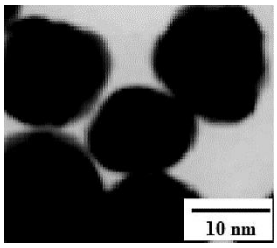

Fig. 4. HRTEM image of ZnS quantum dots.

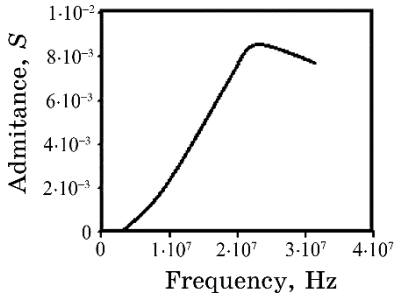

Fig. 5. Filtering behaviour ZnS quantum dots on SBR latex.

TABLE 2. Nanofilter characteristic data for SBR capped ZnS quantum dots.

Sample	Matrix used	Stop band, MHz	Pass band, MHz	Critical frequency (f_c), MHz
ZnS SBR QD	SBR	0 to 20	20 to 32	20

4. CONCLUSIONS

ZnS quantum dots are synthesized on SBR latex matrix using simple, low cost chemical synthesis method. The optical and structural properties of the synthesized quantum dots are studied using standard characterization techniques, from which it was found that the quantum dots have an absorption edge of 225 nm and have a wurtzite structure. The size of the quantum dots are found to be in and around 10 nm that matches with the estimation from the absorption and XRD spectra analysis. To check the nanofilter application of ZnS quantum dots, admittance characteristics of quantum dots are studied and the variation is plotted against changing frequencies. It was noted that SBR capped ZnS quantum dots can successfully act as band pass filter with stop band and pass band frequencies in the range 0–20 MHz and 20–32 MHz, respectively. The critical frequency for the ZnS nanofilter is observed to be around 20 MHz.

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