Performance and Application of quantum-dot light-emitting devices

Mukesh Kumari

ABSTRACT

Light sources based on silicon have been the subject of interest for many years. Silicon would give high volume assembling to commercialization as well as permit complementary metal– oxide– semiconductor (CMOS) similarity empowering joining of light sources inside CMOS hardware. Colloidal semiconductor nanocrystals have limit emanation spectra which settles on them a superb decision for dynamic media in optoelectronic applications. Besides, arrangement process capacity of colloidal quantum specks makes preparing and reconciliation on the silicon stage simpler. This paper talks about the plan and manufacture of colloidal quantum spot based light-radiating devices utilizing inorganic materials on a silicon stage for unmistakable wavelengths. The outcomes exhibit the capacity to coordinate colloidal quantum specks on silicon which would permit the advancement of smaller light hotspots for optical correspondence.

Keywords: quantum-dot, light-emitting devices, photonics.

INTRODUCTION

Light sources such as LEDs (light-emitting devices) and lasers form an integral part of optical transceivers but silicon-based light sources have remained one of the main challenges for silicon photonics as silicon is a poor light emitter. Silicon has an aberrant bandgap where the base of the conduction band isn't lined up with the highest point of valence band along the wave vector since they have distinctive momenta. A photon with vitality close to the semiconductor bandgap is massless which implies it has right around zero force. Since these photons can't convey gem energy, it requires a third molecule to fulfill the protection of gem force. Along these lines, the electrons need to sit tight for the retention or emanation of a phonon with additional force to recombine with a gap. This procedure lessens the likelihood of radiative recombination and expands the likelihood of non-radiative recombination where abundance vitality is discharged as a phonon to the semiconductor precious stone grid instead of a photon.

The two fundamental non-radiative recombination forms in coordinate semiconductors are Auger recombination and imperfection created non-radiative recombination. Twist drill recombination happens when an electron or gap is eager to a higher vitality level by retaining the discharged vitality from an electron-gap recombination. Notwithstanding this, silicon-based light-producing devices have been shown utilizing top notch mass silicon embedded in a forward one-sided sunlight based cell invigorated Raman dispersing in silicon waveguides particle implantation in a silicon p-n intersection silicon nanocrystals in a dielectric lattice and Er (Erbium) coupled to silicon nanocrystals in a dielectric. Be that as it may, these strategies have their impediments, for example, low increase, inadmissible wavelength district for optical correspondence, and room temperature task issues.

Silicon photonics is another way to deal with utilizing light to transmit information rather than electrical signs. The regularly expanding interest for more prominent data transfer capacity, phenomenal versatility of optical fiber, disappointment of copper to scale higher velocities, and the capacity to transmit vitality more productively utilizing light as opposed to power is the main thrust behind silicon photonics. In addition, because of its similarity with the develop coordinated circuit (IC) producing industry, silicon photonics offers the capability of making minimal effort photonics for mass market applications . The improvement of CMOS-coordinated optical devices, for example, wavelength division multiplexers, electro-optical modulators, photograph finders and fiber edge couplers has permitted solid mix of profoundly scaled optical circuits (Fig. 1).
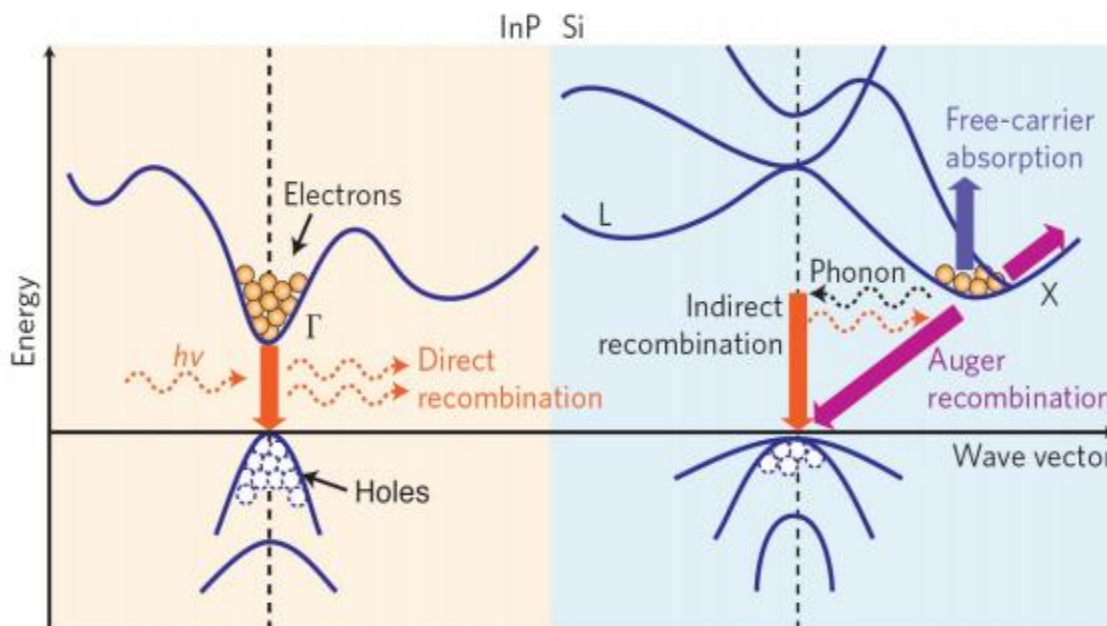
Figure 1: Energy band diagrams and carrier transition processes in indium phosphide (InP) (left) and silicon (right)

BACKGROUND THEORY AND DEVICE DESIGN

Quantum dots have a radius smaller than the characteristic Bohr exciton radius which gives rise to quantum confinement effects. This outcomes in restriction of the transporters in every one of the three bearings and changes the thickness of states. Dissimilar to mass semiconductors, which have a consistent thickness of states, the three-dimensional (3D) quantization in a quantum dab offers ascend to a delta-formed thickness of states without any states in the middle of the delta crests. In this way, these quantum dabs which are sufficiently little bits of semiconductor utilize physical control to approach iota like conduct. This is like the rudimentary issue of "the molecule in the container" in quantum mechanics.
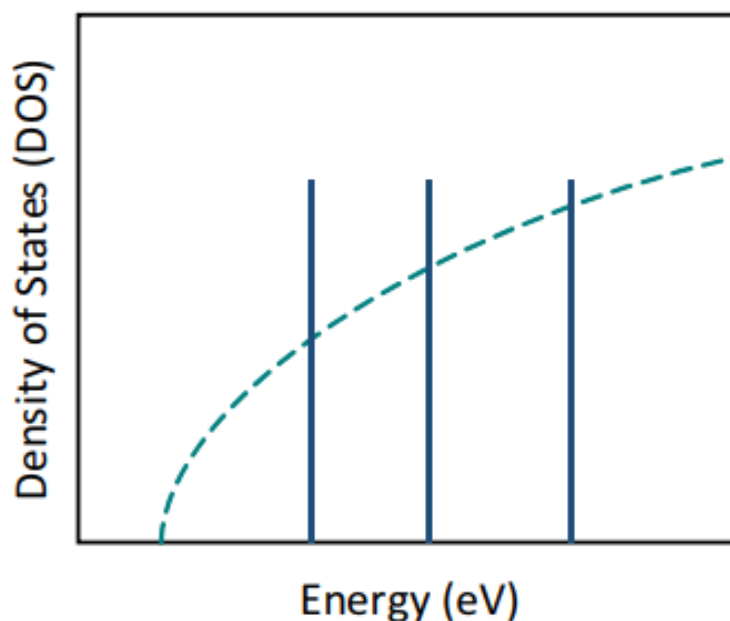

Figure 2: Schematic diagram illustrating the representation of the electronic density of states (DOS) of quantum dots (delta-like peaks) and bulk semiconductors (dashed).

For a quantum dot, an electron confined in all directions has no free motion which results in no k-space being available for free electrons to occupy. Therefore, each quantum state of a zero-dimensional (0D) system such as this can be occupied by only two electrons. The density of states is thus described by the delta function as follows:

$$D^{(0)}(E) = 2\delta(E - E_c)$$

For more than one quantum state, the density of states is given by

$$D^{(0)}(E) = \sum_n 2\delta(E - E_c)$$

The density of states for the quantized 0D electron system was shown in Figure 2. The density of states is further applied to both the valence band and conduction band of a material to obtain the joint density of states (JDOS). The JDOS determines the optical and electronic properties of the material.

PROPERTIES OF QUANTUM DOTS

The optical properties, such as absorption and emission, of the colloidal QDs are governed by the quantum confinement effect. The optical properties of colloidal QDs change with measure. This fundamental wonder can be comprehended by considering the vulnerability connection amongst position and force for nothing and kept particles. For a free molecule, force can be definitely characterized though the vulnerability in position increments. For a limited molecule, the vulnerability in position diminishes while force vulnerability increments. This enables us to see discrete energies of a molecule as a superposition of mass force states which brings about pressure of adjacent changes permitting single extraordinary progress in the molecule.
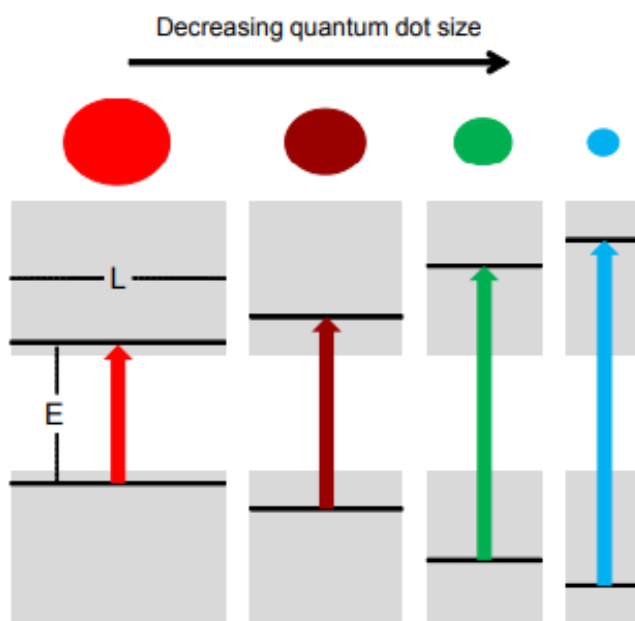

Figure 3: Schematic of the effect of the decreased size of the box or the dot on the increased energy gap of a semiconductor quantum dot. Decrease in size (from left to right) shows increase in bandgap and decrease in wavelength of light emitted.

The effect on optical properties due to the change in bandgap energy with change in size can be further understood by modeling the quantum dot using "particle in the spherical well" where the potential inside the well is zero. Brus developed the approximate relationship between the energy bandgap and particle size [23] and the relationship for the lowest excited state energy is given by:

$$E = E_{bulk} + \frac{\hbar^2 \pi^2}{2a^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) - \frac{1.8e^2}{4\pi\epsilon\epsilon_0 a} + polarization\,terms$$

FABRICATION AND SYNPAPER

The most successful method of preparing nanocrystals of high quality and a high degree of monodispersity is by organo-metallic synpaper. This process involves combining an organometallic precursor with a corresponding chalcogen precursor in a boiling solvent at high temperatures as shown in Figure 4.
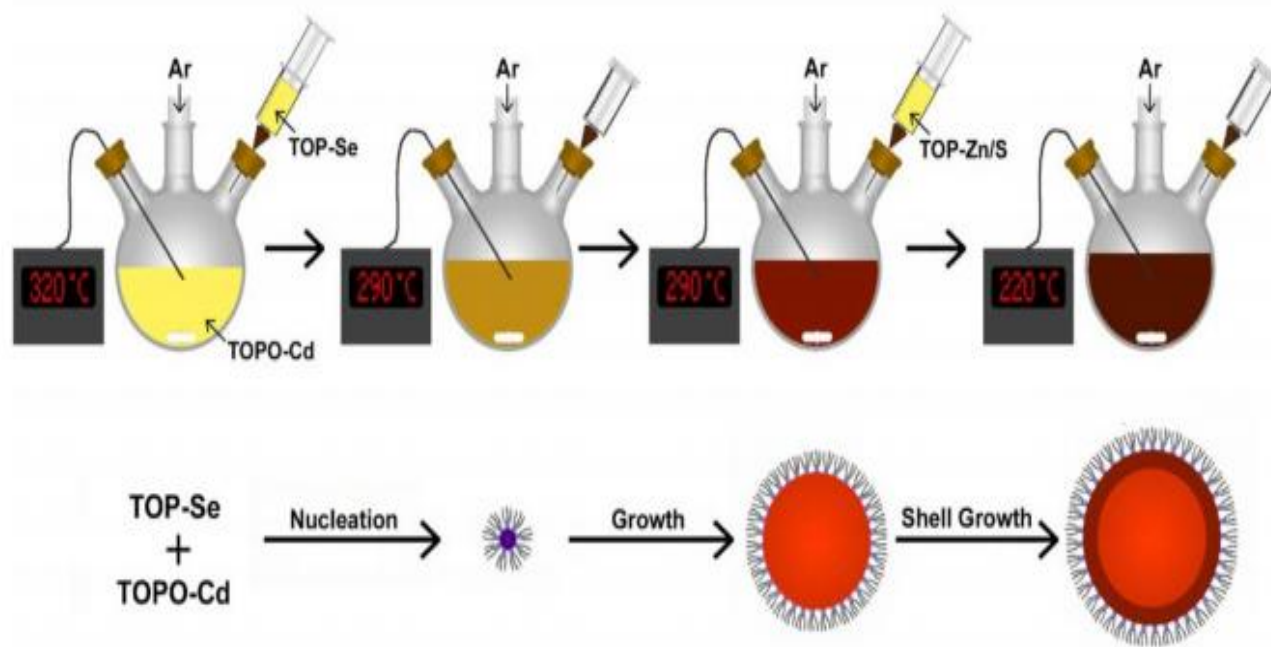

Figure 4: Synpaper of colloidal CdSe quantum dots

The size of the QD can be monitored during the growth period using a spectroscopic probe within the reaction flask or by examining aliquots (a sample or a portion of the total amount of a solution) taken at various intervals [14]. The development can be ceased once the coveted size has been come to by basically taking out examples at specific circumstances from the response jar. The development rate and molecule estimate esteems can be tuned by controlling the underlying antecedent focus, the development temperature and the length of the development time frame or by bringing extra forerunner material into the response vessel amid the development time frame. After the coveted size is gotten, the QDs are surface passivated to enhance the fluorescence yield by the storing an inorganic topping layer.

The topping layer is acquired by infusing antecedents, for example, zinc and sulfur broke down in TOP. This topping layer shapes the shell and is made of a semiconductor material of more extensive bandgap than the center material. These center shell structures with effective surface passivization increment the likelihood of radiative recombination by giving better transporter imprisonment inside the QD center. The QDs are steady in air in spite of the fact that the responses completed to create the QDs are performed under an idle climate. This enables QD to be utilized moderately effortlessly for different applications. In this way, utilizing this procedure, the size and state of the nanocrystals can be profoundly controlled by picking the correct antecedent reagents, topping ligands and controlling the temperature and time.

General Device Fabrication

This segment portrays the creation of different colloidal QD-based LEDs in detail. The creation of a normal colloidal QD LED includes designing and keeping a colloidal QD layer, saving charge transport layers and contacts to infuse charges proficiently. This area portrays the formula and creation devices utilized for manufacturing colloidal QD LEDs.
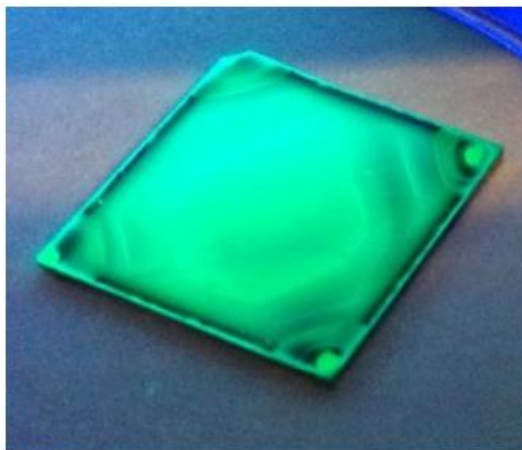
Figure 5: Sample under UV excitation after spin-coating the colloidal QDs.

The creation procedure began with dissolvable cleaning the silicon wafer with CH3)2CO at 55 oC for 10 minutes, methanol for 5 minutes and flushing with DI water. The silicon wafer in the wake of cleaning was heated for 1 minute at 125 oC for drying out and after that cut into 12 mm x 12 mm pieces. The examples were then put into a radio recurrence (RF) sputterer and the posterior of the examples were sputtered with Al at an energy of 200 W for 20 minutes under argon (Ar) climate. This procedure yielded 225 nm of thick Al covering on the back utilized for back contact. The back contact was then tempered at 400 oC for 60 seconds utilizing a Jipelec RTP (quick warm processor) under N2 climate which maintains a strategic distance from encourage oxidation of metal amid strengthening and can likewise decrease any interfacial oxide between the metal and semiconductor. High-temperature toughening decreases the obstruction at the metal-semiconductor interface and subsequently diminishing the contact resistivity.

CONCLUSION

In this paper, design and manufacture of colloidal QD-construct light-producing devices in light of silicon substrate have been studied. This paper showed the capacity to incorporate colloidal QDs with silicon which would permit the utilization of built up progress CMOS innovation. The utilization of CMOS innovation would thusly permit high volume assembling of conservative light sources utilized as a part of optical correspondence. The one of a kind properties of colloidal QDs, for example, wide tunability, high photoluminescence (PL) proficiency make the QDs an extraordinary possibility for utilizing as a dynamic material in the light-emanating devices. Colloidal QDs additionally permitted arrangement process ability which makes joining with a silicon stage extremely viable. The materials for the device structure were guaranteed the productive infusion of charges. The device structure comprised of p-type silicon, CdSe/Zns as the dynamic material, SiO2 as the opening transport layer and ZnO as the electron transport layer, individually, lastly Al as contacts. The colloidal QD utilized structures a sort I heterojunction which permits restriction of charge transporters and expands the likelihood of radiative recombination. The opening and electron transport have higher bandgaps than the dynamic material, in this manner permitting productive infusion of rushes into the dynamic district.

Alongside outline and manufacture, designing of colloidal QDs is critical for making proficient LEDs. This paper displayed different techniques which could be utilized for successfully designing quantum spots. The best method for designing these dabs for micron determination has experienced smaller scale contact printing. This paper additionally exhibited the disappointment of colloidal QDs liftoff after photolithography, however then again, effectively showed nanoscale designing of colloidal QDs utilizing ebeam lithography. The nanoscale designing permits controlled position of these colloidal QDs utilized for different single photonic and plasmonic applications.

REFERENCES

[1]. J. E. Halpert, Design and synpaper of nanocrystal heterostructures for optoelectronic applications. Ph.D. paper, Massachusetts Institute of Technology, 2008.
[2]. C. Murray, S. Sun, W. Gaschler, H. Doyle, T. Betley, and K. C.R., "Colloidal synpaper of nanocrystals and nanocrystal superlattices," IBM Journal of Research and Development, vol. 45, pp. 47–56, 2001.
[3]. Y. Shirasaki, G. J. Supran, M. G. Bawendi, and V. V. Bulovic, "Emergence of colloidal quantum-dot light-emitting technologies," Nature Photonics, vol. 7, pp. 13–23, 2012.

[4]. S. Coe-Sullivan, "Quantum dot development," Nature Photonics, vol. 3, pp. 315–316, 2009.

[5]. C. Dang, J. Lee, C. Breen, J. S. Steckel, S. Coe-Sullivan, and A. Nurmikko, "Red, green and blue lasing enabled by single-exciton gain in colloidal quantum dot films," Nature Nanotechnology, vol. 7, pp. 335–339, 2012.

[6]. T. Rauch, M. B¨oberl, S. F. Tedde, J. Furst, M. V. Kovalenko, G. Hesser, U. Lemmer, ¨ W. Heiss, and O. Hayden, "Near-infrared imaging with quantum-dot-sensitized organic photodiodes," Nature Photonics, vol. 3, pp. 332–336, 2009.

[7]. S. Keuleyan, E. Lhuillier, V. Brajuskovic, and P. Guyot-Sionnest, "Mid-infrared HgTe colloidal quantum dot photodetectors," Nature Photonics, vol. 5, pp. 489–493, 2011.

[8]. V. Sukhovatkin, S. Hinds, L. Brzozowski, and E. H. Sargent, "Colloidal quantum-dot photodetectors exploiting multiexciton generation," Science, vol. 324, pp. 1542–1544, 2009.

[9]. B. Jalali and S. Fathpour, "Silicon photonics," Journal of Lightwave Technology, vol. 24, no. 12, pp. 4600–4615, 2006.

[10]. Y. A. Vlasov, "Silicon CMOS-integrated nano-photonics for computer and data communications beyond 100G," Communications Magazine, IEEE, vol. 50, no. 2, pp. 67–72, 2012.

[11]. D. Liang and J. E. Bowers, "Recent progress in lasers on silicon," Nature Photonics, vol. 4, no. 8, pp. 511–517, 2010.

[12]. M. A. Green, J. Zhao, A. Wang, P. J. Reece, and M. Gal, "Effcient silicon light-emitting diodes," Nature, vol. 412, pp. 805–808, 2001.

[13]. H. Rong, R. Jones, A. Liu, O. Cohen, D. Hak, A. Fang, and M. Paniccia, "A continuouswave Raman silicon laser," Nature, vol. 433, pp. 725–728, 2005.

[14]. W. L. Ng, M. A. Lourenc, R. M. Gwilliam, S. Ledain, S. G., and K. P. Homewood, "An efficient room-temperature silicon-based light-emitting diode," Nature, vol. 410, pp. 192–194, 2001.

[15]. R. Marcus, "Chemical and electrochemical electron-transfer theory," Annual Review of Physical Chemistry, vol. 15, no. 1, pp. 155–196, 1964.

[16]. A. M. Kuznetsov and J. Ulstrup, Electron Transfer in Chemistry and Biology: An Introduction to the Theory. Chichester: Wiley, 1999.

[17]. Y. Shirasaki, G. J. Supran, M. G. Bawendi, and V. Bulovi´c, "Emergence of colloidal quantum-dot light-emitting technologies," Nature Photonics, vol. 7, no. 1, pp. 13–23, 2012.

[18]. X. Zhou, J. He, L. Liao, M. Lu, Z. Xiong, X. Ding, X. Hou, F. Tao, C. Zhou, and S. Lee, "Enhanced hole injection in a bilayer vacuum-deposited organic light-emitting device using a p-type doped silicon anode," Applied Physics Letters, vol. 74, no. 4, pp. 609–611, 1999.

[19]. I. Parker and H. H. Kim, "Fabrication of polymer light-emitting diodes using doped silicon electrodes," Applied Physics Letters, vol. 64, no. 14, pp. 1774–1776, 1994.

[20]. A. Gopal, K. Hoshino, S. Kim, and X. Zhang, "Multi-color colloidal quantum dot based light emitting diodes micropatterned on silicon hole transporting layers," Nanotechnology, vol. 20, no. 23, p. 235201, 2009.

[21]. A. Gopal, K. Hoshino, and X. Zhang, "Photolithographic patterning of subwavelength top emitting colloidal quantum dot based inorganic light emitting diodes on silicon," Applied Physics Letters, vol. 96, no. 13, p. 131109, 2010.