Development of Silicon-Integrated Infrared Quantum Dot Light Emitting Diodes

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We have designed and fabricated solution processed infrared light emitting diodes (LED) based on colloidal PbSe nanocrystal quantum dot (NQD). The infrared LED has its important application at optoelectronic communication considering the communication wavelength of 1.3 and 1.55 μm. The solution processed quantum dot light emitting diode (QD-LED) has the feature of low cost, easy processing, emission size-tunable and compatible with various substrates. Since silicon is the mainstream material to be used in electronic devices, we have integrated our device with silicon in which silicon serves as the anode and supporting substrate. This is of interest for chip-to-chip and board-board optical interconnections and in fiber-optic and optical wireless communications.

The silicon based device structure is Si/ITO/PEDOT/MEHPPV + PbSe NQD/Alq3/Ca/Al (Figure 2). The Si/ITO serves as the anode and Ca/Al as the cathode, respectively. The electron transport layer is Alq3. PbSe NQD is the emission material and emits infrared light upon current injection. The conducting polymer, MEHPPV, works as the hole transport layer and supporting matrix to form uniform interpenetrating network on nanoscale. The additional visible light emitted by MEHPPV is filtered by double-side polished silicon. Figure 3 shows the device electroluminescence with a center wavlength at ~1.55 μm and a FWHM of ~140nm. The silicon-based PbSe LED can emit light very effectively and has an external quantum efficiency of ~0.01%.

The PbSe NQD used in this experiment is synthesized by the non-coordinating solvent technique[1]. The resulting PbSe nanocrystals were stabilized with a capping layer of oleate molecules coordinated to the Pb atoms. The QD emission wavelength is tunable by controlling QD size. The synthesized colloidal QDs generally exhibit very high internal quantum efficiency (>80%) and emission stability due to three-dimensional quantum confinement. The device fabrication starts from spin casting PEDOT and MEHPPV/QD layers respectively. Then the Alq3 and Ca/Al layers are added by thermal deposition. The whole process is solution processed and is cost effective.

To explore the infrared emission mechanism we measured the time-resolved photoluminescence of MEHPPV in MEHPPV/PbSe mixing solution. It is found that the lifetime of MEHPPV photoluminescence is significantly reduced by mixing with PbSe NQD. This indicates a very effective energy transfer between the MEHPPV and PbSe QD. The excitons, formed in MEHPPV, are transferred to the inorganic QD by energy transfer, (Forster and Dexter process) and recombined to release the infrared light. The energy transfer, via our computation, is proved to be very effective between the two compositions that up to 60% of excitons produced by MEHPPV are transferred to QD phase.

In the future work we will continue improving the device performance by surface engineering of the PbSe QD. Ligand molecules with shorter carbon chain on QD surface are beneficial for energy transfer thus resulting in more efficient infrared light emission. Another work is to confine the emission band width by using a microcavity structure[2] which is more practical for optical communication usage.

As a conclusion, we have successfully fabricated the silicon-based solution processed infrared light emitter based on PbSe NQD. The device shows a strong infrared emission of ~1.55μm under relatively low driven voltage and current. The device is a monolithic integration of optics and electronics on a single silicon chip. And this silicon-based nanoscale light source operating at 1.55 μm is highly desired for future high-speed circuits and systems[3]. Other investigations attempting to improve device performance narrow the emission width is currently underway for practical application.

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Figure 1 (a) TEM picture of PbSe NQD (b) absorption and photoluminescence of PbSe NQD with different sizes

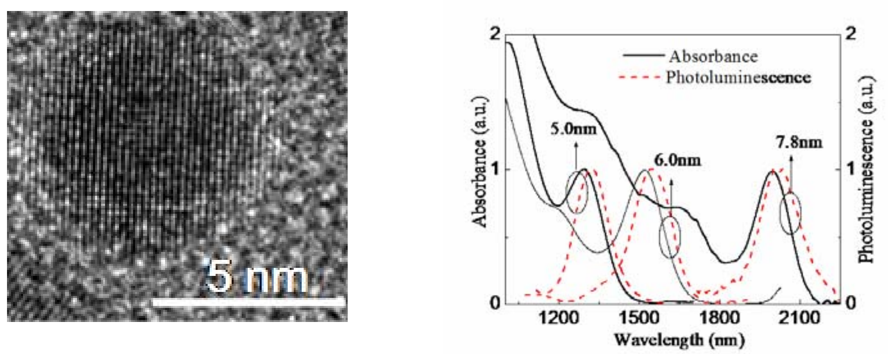

Figure 2: Device configuration (left) and energy band diagram of a NQD-LED employing PbSe nanocrystals as the light emitting medium.

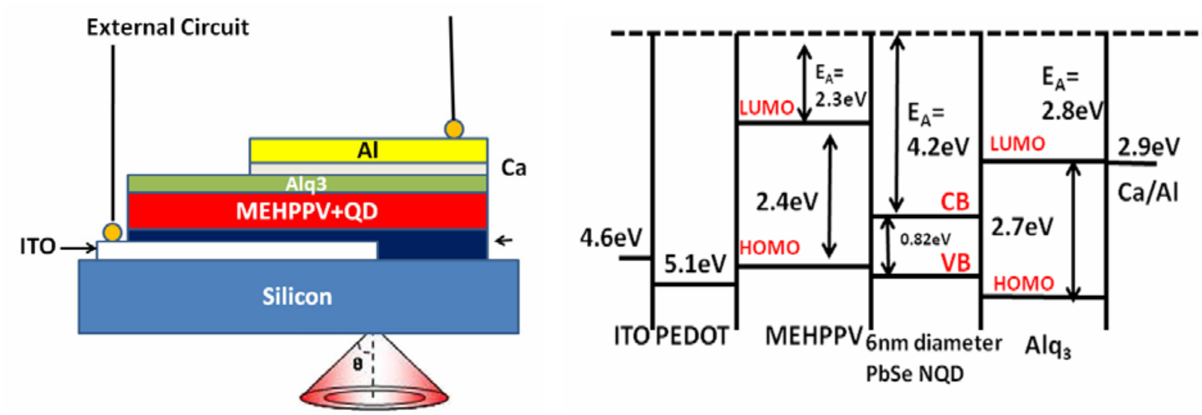

Figure 3: (a) Output spectra of NQD-LED operated at 10mA injection currents which shows a perfect fit with the Gaussian curve as can be seen on the graph. (b) I-V curve of the corresponding device. (c) Time-resolved PL traces of MEHPPV in MEHPPV/QD mixture and pure MEHPPV solution.