

Infrared Colloidal Quantum Dot Chalcogenide Films for Integrated Light Sources

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Abstract: Quantum dots and chalcogenide glasses form the basis for photoluminescent films which are fabricated in microcavities to enhance light emission for coupling into waveguides.

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1. Introduction

Infrared (IR) light sources are desired in the field of chemical-biological sensing because the IR regime is dubbed the “fingerprint” regime, where most molecules show vibrational absorption. Current sources are expensive and do not offer elegant monolithic and CMOS solutions. For a sensor-on-chip device, the development of an integrated IR light source is mandatory. Quantum dots (QDs) and chalcogenide glasses (ChG) involve two emerging areas of microphotonics which can supply the material base for a substrate-independent planar light source. PbS QDs, which emit from 1-2 μm , synthesized at low cost via wet chemistry are deposited in spin deposition CMOS compatible methods. ChGs provide an IR-transparent material from which planar devices are fabricated using CMOS compatible processes [1].

We demonstrate coupling of emission from QDs to ChG through common solution dissolution of QDs and ChGs followed by spin-coating and incorporation of QDs embedded within a polymer such as PMMA (poly methyl methacrylate) into a multilayer stack with ChGs.

Enhancement of the quantum dot emission is achieved through use of a microcavity. This has been demonstrated before using silica microspheres coated with visible emission CdSe QDs [2]. We use ChG planar microdisk cavities with Q-factors as high as 10^5 [3]. Photonic crystal cavities are also fabricated in ChG materials using focused ion beam (FIB) milling.

2. QD/ChG Films

Solutions of QDs within ChG are obtained by mixing separate solutions of QDs and ChGs, such as germanium antimony sulfide and arsenic sulfide, which were dissolved in the same solvent. Due to the ease of dissolution of ChG by amines [4], the common solvents tested are ethanolamine (ETA), ethylenediamine (EDA), and propylamine (PA). Our data on the solubility of QDs and ChGs in these common solvents reveal that the QDs are soluble only in PA. We attribute this insolubility of QDs in ETA and EDA to unfavorable chemical interactions between the solvents and the organic capping ligands present on the surface of the QDs. Even though solutions of QDs and ChG in PA are stable separately, once they are mixed together, some agglomeration of QDs occurs as shown in Figure 1.

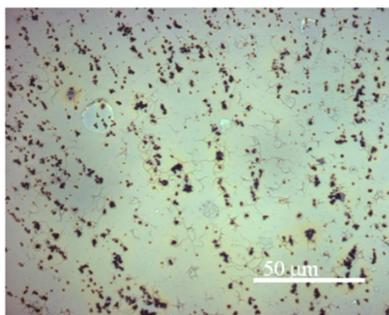


Figure 1: Optical micrograph of PbS QD doped GeSbS film fabricated from spin deposition of single solvent solution. Even though solutions are stable separately, once mixed, QD agglomeration occurs causing formation of QD clusters in the film.

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Films are formed by spin deposition onto a substrate and subsequent annealing steps. QDs are also embedded within a PMMA matrix and sandwiched between two layers of ChG. PMMA has previously been shown to passivate and stabilize QDs while forming uniform films [5]. Schematics of these two structures are shown in Figure 2. ChG films can be deposited either by thermal evaporation or spin deposition.

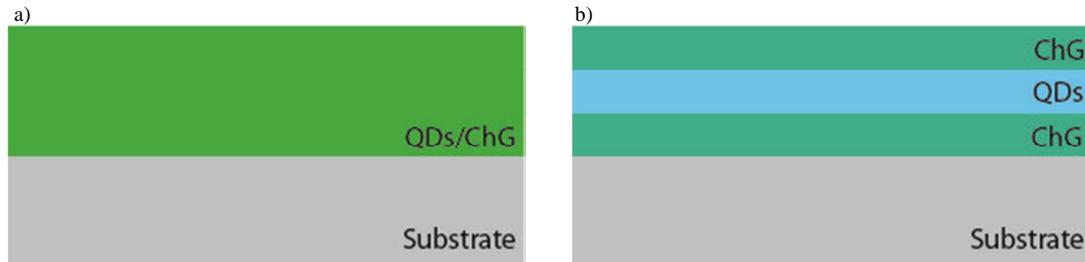


Figure 2: Schematic of the two approaches to incorporate QDs and ChGs to create a platform for light source devices. (a) Single layer structure of films fabricated from single solvent solutions of QDs and ChG. (b) Multilayer structure of films fabricated from subsequent depositions of ChG and QDs embedded in PMMA matrix

The photoluminescence (PL) from both single layer and multiple layer stack films were found to be comparable in magnitude as seen in Figure 3. Even though some agglomeration is present in the QD doped ChG films, PL was not completely quenched. Both film structures are viable paths towards yielding an integrated IR light source.

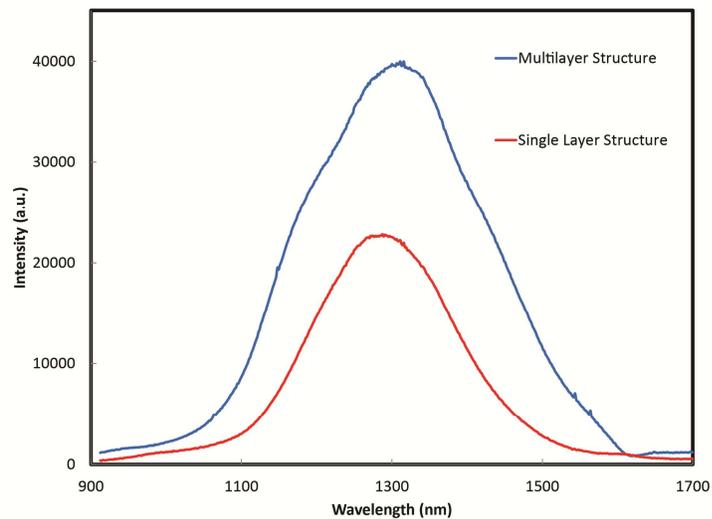


Figure 3: Photoluminescence of single layer and multilayer structure films using an excitation laser at 650 nm wavelength with an optical power of less than 2 mW. Emission intensity is comparable for both films showing both approaches are viable platforms for integrated devices.

3. Integrated Device Designs

We have previously fabricated ChG microdisk resonators with Q-factors as high as 2×10^5 [3]. Efficient coupling from the resonator to the waveguide is achieved using a pulley coupler design as shown in Figure 4a. Microdisk resonators are fabricated from both single layer and multilayer film structures based on ChG materials. QD light emission is enhanced for wavelengths corresponding to the resonant “whispering-gallery” modes. The enhanced PL can be coupled from the resonator to an adjacent waveguide where it is guided “on-chip” to other devices such as optical sensors. A schematic of a single layer QD/ChG microdisk resonator light source coupled to a waveguide is shown in Figure 4b. Photonic crystals have previously been shown to enhance QD emission in silicon microcavities fabricated using e-beam lithography [6]. In our work emission enhancement is shown for photonic crystals fabricated in QD/ChG films.

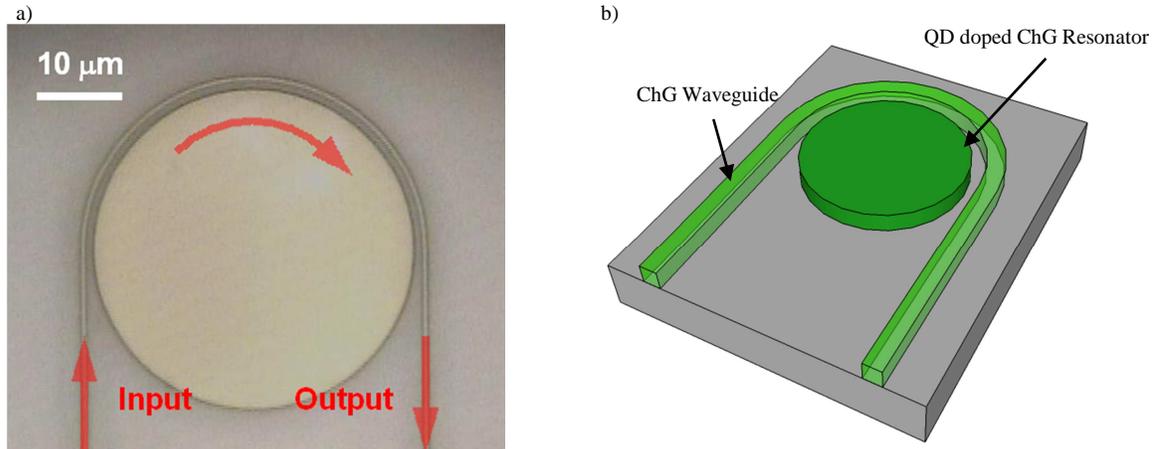


Figure 4: (a) Optical micrograph of a high Q-factor ChG resonator with a pulley coupled waveguide [3]. (b) Schematic of an integrated QD light source. Light emission from QDs is enhanced in the QD doped ChG resonator and is coupled to a ChG waveguide where it can be guided to other devices “on chip”.

4. Conclusions

QDs and ChGs provide the basis for an integrated IR light source. QDs are incorporated with ChGs through both single solvent solution deposition and multilayer stack structures with QDs embedded in PMMA. Both QD doped ChG single layer and QD doped polymer multilayer structures show photoluminescence. Microcavities, such as microring resonators and photonic crystals, enhance QD light emission. Integrated light sources are fabricated through coupling of emission from the cavity to a waveguide.

5. Acknowledgement

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6. References

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