Single Quantum Dot Spectroscopy in a Standard Macro-photoluminescence Setup

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Solotronic [1,2] studies require access to single quantum emitters such as single defects or single quantum dots (QDs). The most common procedure is based on optical spectroscopy of a single emitters and application of micro-photoluminescence (μPL) setups. This can be technically realized either by microscopic objective placed outside the cryostat or miniature lens placed on piezo positioner in front of a sample. Above realizations are rather expensive and are not ideal in terms of photon extraction efficiency, stability and complexity.

In this work we present a new approach based on in-situ fabrication of micro-optic structures made of transparent resin placed on top of a semiconductor heterostructure. Micro-optic objects were produced with usage of three dimensional direct laser writing (3D-DLW) technique. The 3D-DLW is based on a two-photon absorption process which induces polymerization of a photoresist. In association with system that provides fast and accurate positioning of polymerization spot it allows printing arbitrary shaped 3D transparent structures. The great advantage of such polymer-micro optics is an ease of scaling up. Once printed structures can be used as a moulds for replication or masters for pattern transfer.

We demonstrate potential of proposed approach on self-assembled CdSe/ZnSe QDs. Placing spherical micro-lenses on a cylindrical support combined with an ordinary external lens fulfill imaging conditions for QDs placed 50 nm below surface of a sample. As a result presented "micro-bullet" structures allow studying PL of a single dot collected from the spot smaller than 1 μm but with standard macro PL setup.

We also demonstrate modifications of presented structures e.g. Fresnel lens geometry instead of spherical one or variation of a radius, and discuss photon extraction coefficient enhancement as well as combining 3D-DLW with single-color in-situ photolithography marking of an individual QD [3].

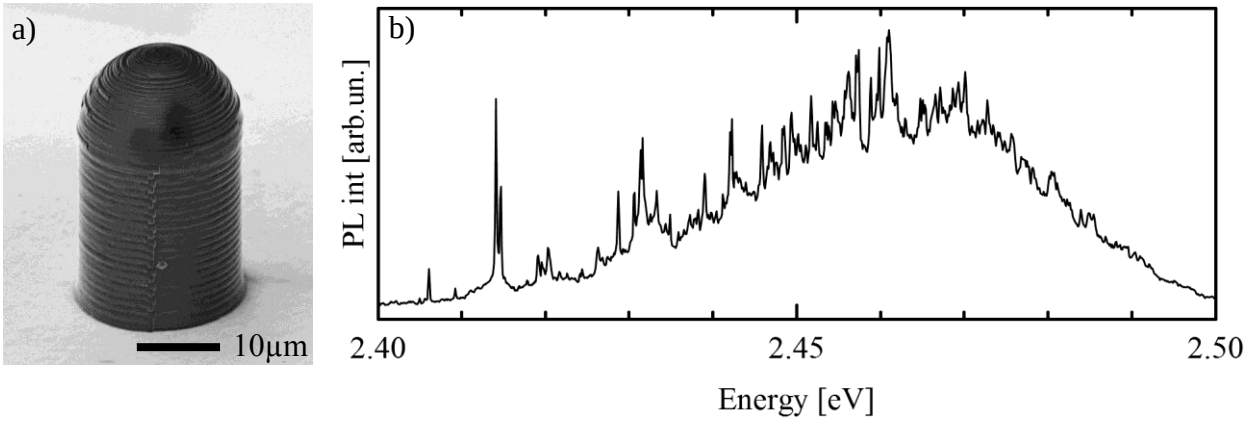

Fig. 1 a) Example SEM image of a "micro-bullet" structure fabricated by 3D-DLW technique, (b) corresponding spectrum of single QDs obtained in standard macro-PL setup.

[1] J. Kobak, *et al.*, *Nat. Comm.*, **5**, 3191 (2014)
[2] T. Smoleński, *et al.*, *Nat. Comm.*, **7**, 10484 (2016)
[3] K. Sawicki *et al.*, *Appl. Phys. Lett.*, **106**, 012101 (2015)