Field-Effect Transistors of Lead Chalcogenides Quantum Dot Nanocubes and Core@Shell Nanocrystals Assemblies

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Colloidal quantum dots (CQD) assemblies emerge as a new type of hybrid solid thin films that exploit the size-dependent quantum confinement properties of the individual QDs: energy bandgap variations and formation of discrete energy sub-bands. While these materials have been around for 30 years, their applications are limited only for optical or biological use. It has just been recently that these materials are being applied for displays with better color gamut than organic semiconductors,[1] photovoltaics,[2] and photodetectors. Nevertheless, the materials choices for these electronic devices are still limited, which for latter case are still mostly exploit the well-known quasi-spherical PbS QDs. Efforts to study charge transports of PbS QDs using field effect transistors have made significant progress.[3-5] Meanwhile, the properties of many other QDs, including the other lead chalcogenides, have yet to be investigated.

Here we demonstrate FETs of colloidal QDs using various form factors of lead chalcogenide nanocrystals in order to clarify the influence of the shapes, couplings, and assembly conformations towards the charge carrier transport properties. Electron transport characteristics of PbS quasi-spherical QDs and PbS nanocubes are compared using both conventional approach to fabricate solid gate FETs as well as FET using ionic liquid gate. The surface stoichiometry difference between the two form factors lead to variations of intrinsic carrier density as well as the transport behavior. As found also using PbTe nanocubes, the uses of different ligands make variations in the assembly conformations of the QDs, such as face-on-face coupling and nodes-to-nodes coupling. They are also reflected from the contrasting transport properties, which one of them behaves as ambipolar transport, while the others shows quasi-metallic behavior that weakly modulated by gate voltage. In addition, we also show the first demonstration of FETs using core@shell QDs, in which PbTe is alloyed inside PbS shell. In addition to high performing n-type FETs, the utilization of ionic liquid gating also unravel peculiar properties of core@shell QDs that is different from single compound QDs. These findings will broaden the material choices for developments of various electronic devices based on QD assemblies. Furthermore, some of them are also prospective to investigate the physics at nanoscale,[6] such as thermal transport at nanoscale, thermoelectricity, as well as emerging magnetism or superconductivity.

Refs: [1] A. Nurmikko, *Nature Nanotech.* **10**, 1001 (2015) [2] C. Piliego, S.Z. Bisri, et al. *Energy & Env. Sci.* 6, 3054 (2013); [3] S.Z. Bisri, et al. *Adv. Mater.* **25**, 4309 (2013); [4] ibid. *Adv. Mater.* **26**, 5639 (2014); [5] A. Shulga, S.Z. Bisri, et al. *Adv. Electron. Mater.* **2**, 1500467 (2016); [6] M. Kovalenko, et al. *ACS Nano* 9, 1012 (2015)

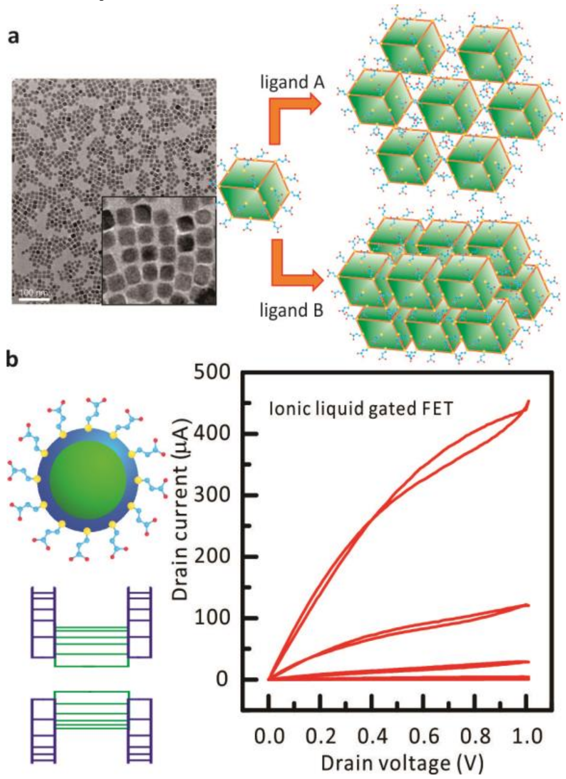

Figure 1 (a) TEM micrograph of PbS nanocubes with oleic acid stabilizing ligand, and a schematic showing that different ligands can lead to different assembly conformation of the nanocubes with different transport properties. **(b)** Schematic of PbTe@PbS core@shell nanocrystal and I_D-V_D FET output characteristics.