Single PbS colloidal quantum dot transistors

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Colloidal quantum dots (CQDs) are sub-10 nm semiconductors treated with liquid processes. CQDs exhibit excellent light emission/absorption characteristics, and their optical bandgaps are widely tunable by adjusting their size. CQDs can be treated by liquid processes, and their functionality can be controlled by selecting suitable ligands [1]. These properties make CQDs attractive candidates for use as transport channels in single-electron transistors (SETs) operating at high temperatures. However, there have been only a few evaluations of carrier transport through single CQDs in transistor geometries because of the technical difficulties in electrically accessing single CQDs prepared by bottom-up methods.

In this work, we report the first demonstration of single-CQD transistors based on commercially available high-quality PbS CQDs with oleic acid as a ligand. We made electrical contact to a single CQD using nano-gap metal electrodes (Fig. 1) and measured single-electron tunneling through the CQDs. The transport characteristics measured at 4 K strongly depend on the quantum dot size; a few-electron regime is observed in small CQDs, while a many-electron regime is observed in large CQDs. From the orbital-dependent electron charging energy and conductance, we demonstrate that the tunneling barrier in this system is formed not only by the capping material but also by the intrinsic gap between the electron wavefunction in the CQDs and electrodes. Moreover, spin-correlated coherent carrier transport (the Kondo effect) has been observed for the first time in the CQD system; this indicates strong coupling between the electrodes and the CQDs despite the use of long-chain insulating oleic acid ligand. These results provide nanoscopic insight into carrier transport through CQDs at the single quantum dot level, which is essential for developing CQD applications in optoelectronic devices, such as solar cells and photodetectors. Furthermore, the large charging energy in small CQDs enables SET operation even at room temperature [2]. Considering that PbS CQDs are excellent emitters and absorbers of light, our device is a platform for room-temperature SETs with good optical properties, increasing the functionality and versatility of single-electron devices. This will bring about innovation in quantum information technology.

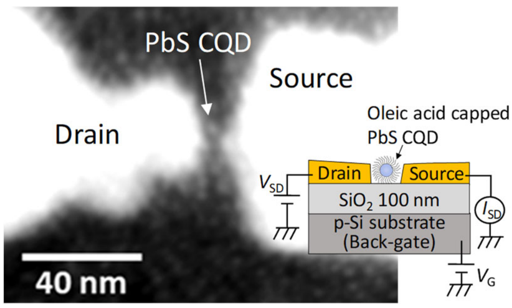

Fig.1. A SEM image of devices. The inset shows schematic illustration of the device structure and experimental setup.

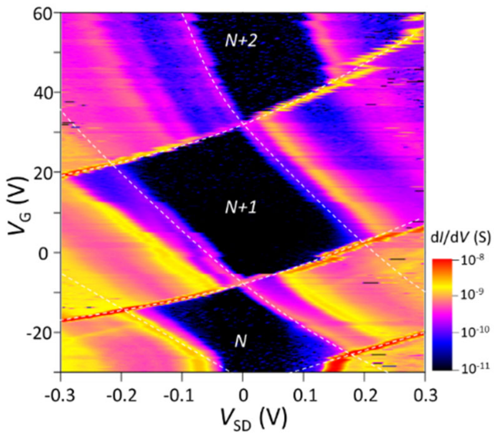

Fig.2. Coulomb stability diagram obtained for a sample with CQD diameter ~ 3.6 nm.

References

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