Electronic transduction mechanism in colloidal-quantum-dot gas sensors

Jingyao Liu, Zhixiang Hu, Huayao Li, Huan Liu*

School of Optical and Electronic Information, Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology (HUST), 1037 Luoyu Road, Wuhan, Hubei, China
Corresponding author: huan@hust.edu.cn

Colloidal quantum dots (CQDs) are promising materials for gas-sensing applications owing to their large surface-to-volume ratio and abundant surface dangling bonds[1]. It is unanimously agreed that the sensing performance of a semiconductor gas sensor can be improved by using semiconductor nanocrystals which promotes its receptor and transducer functions[2]. However, the electronic transduction mechanism has so far been investigated mostly by empirical research, which hinders further development of nanocrystalline semiconductor gas sensors. Here we constructed and characterized an air-stable, NO_2-sensitive thin-film transistor (TFT) based on PbS CQD solids, which enables a quantitative investigation on the electronic transduction mechanism according to the TFT conduction model. The ratio of the average number of electrons transferred across the gas-solid interface produced per unit time at a particular temperature to the number of gas molecules, termed as Electronic Transduction Efficiency (ETE), was calculated to be 5.47×10^{-7} in the case of NO_2-sensitive PbS CQDs at room temperature. We further established a complete depletion model with a flat band diagram to elucidate the transducer function in CQD gas sensors. The CQD-TFT gas sensor exhibited highly sensitive for NO_2 detection at room temperature, with a limit of detection estimated to be 0.5 ppb. This study provides fundamental understanding on electronic transduction mechanism of semiconductor gas sensors.

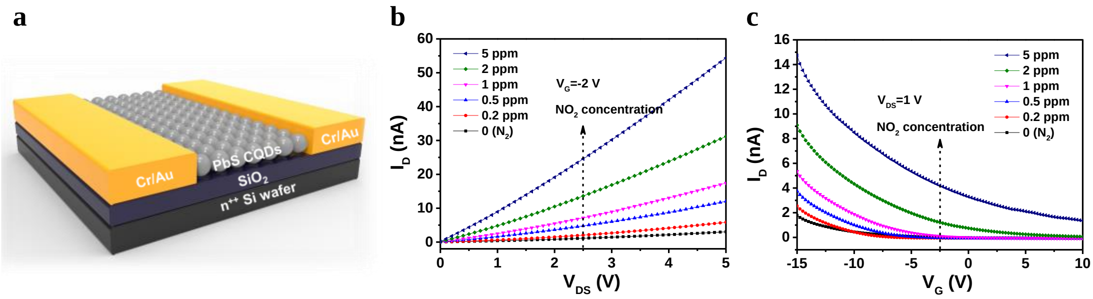

Fig. 1. (a) Schematic illustration of CQD-TFT device. (b) Output and (c) transfer characteristics of the p-channel CQD-TFT exposed to NO_2 concentrations at room temperature.

[1] H. Liu, M. Li, O. Voznyy, et al. Physically flexible, Rapid-Response gas sensor based on colloidal quantum dot solids. Adv. Mater. **26**, 2718-2724 (2014).
[2] N. Yamazoe. New approaches for improving semiconductor gas sensors. Sens. Actuators. B **5**, 7-19 (1991)