OPTOELECTRICAL PROPERTIES OF CdSe-Au NANOROD NETWORKS

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Introduction

Semiconductor colloidal nanocrystals (SCNCs) have been extensively studied in the past decades due to their potential applications in nano-photovoltaic and nano-optoelectronic devices. The ideal case would involve constructing a nano-device with a single nanocrystal as a functional component. Along these lines a single-electron transistor was made from a CdSe nanoparticle [1], while Cui et al. [2] utilized a single CdTe tetrapod for demonstrating such a behaviour. Furthermore, Trudeau et al. [3] studied transistor properties of single CdSe nanorods (NRs) and Steinberg et al. [4] found electrical current switching in single CdSe NRs. The previous capabilities demonstrate feasible nanoelectronic components from single SCNCs.

Using such SCNCs to construct a nano-device remains challenging because, (i) the process to fabricate a device, as reported above, is not easily adaptable to industrial scale production, (ii) it is difficult to control the position and number of SCNCs and (iii) even though we can bridge the gap with a few SCNCs, such structures wouldn't be useable because of their high resistance, caused by the existence of few layers organic surfactants on SCNCs surface.

Recently, Albert et al. [5] have successfully assembled nanocrystals (NCs) end-to-end via a nanowelding approach, mediated by gold (Au) domains; in this case, the resistance between two SCNCs is very small and the length of assembled structure can be controlled in 2D or 3D. This report motivated us to develop a nanodevice with such "welded" nanocrystal networks. Here we present a dielectrophorosis process that affords a controllable assembly of our SCNCs networks in-between nanoelectrodes and demonstrate the detection of their photoconductivity behavior.

Experimental

Fabrication of electrodes

A silicon wafer, covered with a thermally grown 100 nm SiO_2 layer was used as substrate. After chemical cleaning, the wafer was placed on a hot plate and baked at 200°C for 15 minutes to dry completely. Tip-to-tip electrodes were fabricated by employing electron beam lithography and optical lithography, in combination with standard lift off techniques. The electrode structures were prepared by evaporation of 5 nm thick Ti metal, followed by a 50 nm Au layer.

Nanocrystal networks

CdSe-Au networks were synthesized by a colloidal chemistry method [5]. It entails a two steps process in which we first synthesized colloidal CdSe NCs. These were used as seeds in a second reaction in which we injected more Cd and Se precursors in the hot solution to obtain the NRs. The Au domain was deposited on the tips of CdSe NRs to form dumbbell-like structures. A suitable quantity of Iodine was dropped into the as-prepared dumbbell solution; while destabilizes the Au domain, promotes the nanowelding of such NRs.

Characterization

The synthesized CdSe-Au networks were characterized by transmission electron microscopy (TEM; JEM 1011, JEOL). A Suess probe station was employed to contact the two electrodes and a lock-in amplifier (SR7265, AMETEK Inc.) provided the AC voltage for trapping networks. After the trapping, the chip was annealed at 250°C for 15 minutes under N_2 atmosphere. Scanning Electron Microscopy (SEM) was used to observe the morphology of fabricated electrodes and those with trapped networks. A Keithley 2612 meter was used to measure the electrical properties of the device in two-probe geometry. All I-V curves were taken in air and at room temperature. For photo-electrical properties, a 473 nm (blue) laser was used to irradiate the device. The intensity of the laser was about 10 mW/cm^2.

Results and Discussion

A typical TEM image of the as-synthesized CdSe-Au networks is shown in Fig. 1a; chain-like networks can be clearly seen. CdSe NRs were joined by Au domains. With such a connection, the contact resistance between NRs is much lower than that between two

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isolated NRs. This is a significant progress for constructing a nano-device, as it minimizes the raised contact resistances found before. The average size of the networks can be tailored to match the electrodes' spacing by adjusting the synthesis parameters.
Fig. 1b presents a SEM image of fabricated tip-to-tip electrodes; the gap-size is about 100 nm. Numerous trapping results show that the quantity of trapped

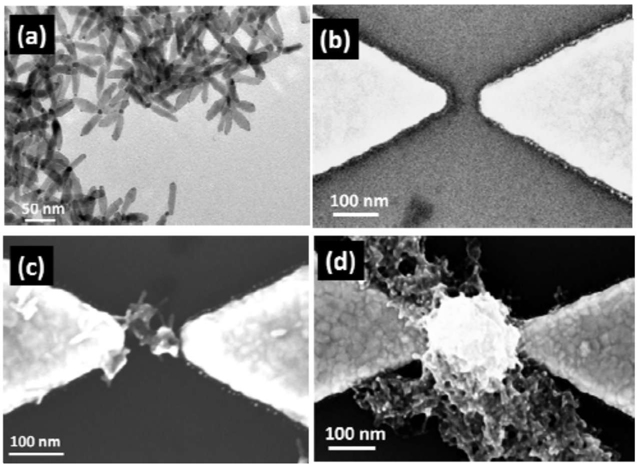

Fig. 1 (a) TEM image of as-synthesized CdSe-Au nanorod networks, (b) SEM image of tip-to-tip electrodes with gap-size about 100 nm, (c) SEM image of a few trapped networks and (d) SEM image of a large quantity of trapped networks in- between planar electrodes.

networks can be modified by adjusting the dielectrophoresis parameters. The most sensitive parameter was the voltage amplitude (V_{RMS}). Below 3 V_{RMS}, no trapping of networks was observed. Above this threshold, the quantity of trapped networks increased with increasing voltage. Exceeding 8 V_{RMS} led to damage of the electrodes. Our best set of parameters for trapping the CdSe-Au networks was a frequency of 1 kHz, 3 V_{RMS} and trapping time of 60 s. Figs. 1c-d are SEM images of electrodes with trapping parameters of 1 kHz, 60 s, 3 V_{RMS} and 5 V_{RMS}, respectively. It is clear that networks bridged two electrodes and an electrical route was established. The chip was then annealed. Inset of Fig. 2 shows the schematic diagram of the photoconductivity measurements device. A typical I-V characteristic of the structure is shown in Fig. 2. The resistance of the device is very high in the absence of blue laser light, but, the resistance decreases a lot by illumination.

Conclusion

CdSe-Au networks were synthesized by colloidal chemistry. In this structure, CdSe NRs are joined by a nanowelding approach, mediated through a Au domain. AC dielectrophoresis was employed to assemble CdSe-Au networks between Au electrodes separated by a ~100 nm distance. The optoelectrical properties were measured for this device. A switchable photoconductive behavior is resolved under

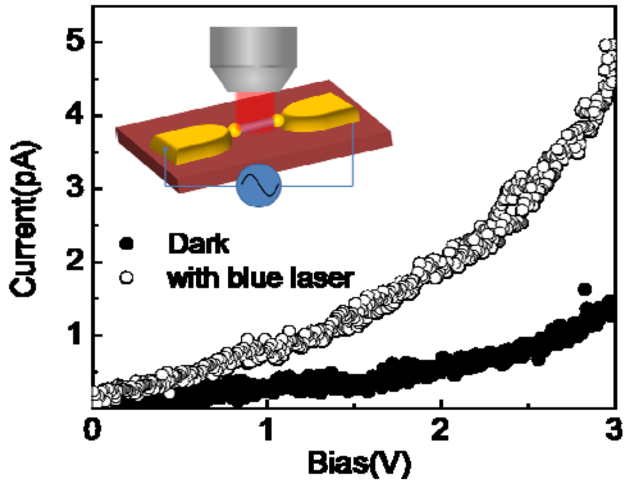

Fig. 2 Room temperature I-V curves with (open circles) and without (filled circles) blue laser irradiation. Inset: schematic drawing of the optoelectrical transport properties measurement setup.

irradiation with a blue laser, demonstrating a new process for using CdSe-Au networks as functional components in optoelectronic nanodevices.

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