The International Society for Optical Engineering

SPIE Newsroom

10.1117/2.1200701.0514

Single carbon nanotube infrared detectors

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A newly developed nanorobotic manipulation system allows the fabrication of an IR detector with high sensitivity and low noise.

Due to their unique hollow cylindrical structure, carbon nanotubes (CNTs) are considered very promising for many potential nano-electronics and nano-device applications. Their optical properties have been extensively explored by absorption spectroscopy[1] and Raman scattering,[2] and their photoconductivity under infrared illumination has also attracted considerable interest since CNTs can potentially be used as superb infrared detector materials characterized by high sensitivity and low noise.

Single-wall carbon nanotube (SWNT) films are now being used for photodetection. However, since it is difficult to fabricate CNT films in which all nanotubes have similar properties, they are typically plagued by poor performance. Theoretical studies have shown that the photoconductivity of individual SWNTs perform much better than CNT films, but the fabrication process of SWNT-based detectors is usually complicated and inefficient. As a result, the R&D scope of single CNT-based IR detectors has been significantly limited.

However, advances in atomic force microscopy (AFM)-based nanorobotic manipulation systems[3,4] have allowed the recent development of a new deterministic process that can reliably and efficiently fabricate single CNT-based nano-infrared detectors.[5]

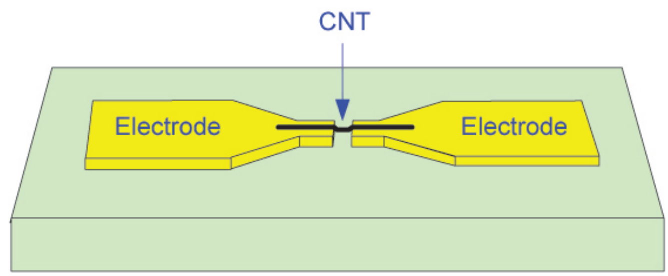

Figure 1. *Diagram of an individual SWNT-based IR detector.*

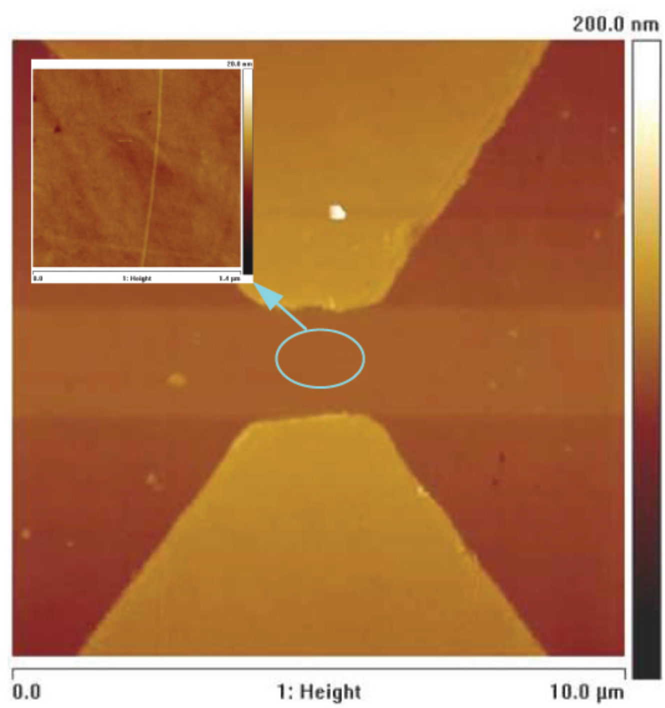

Figure 2. *An AFM image of an individual SWNT-based IR detector. Inset: AFM image of the area between the electrodes.*

Detector design and fabrication

The design of an individual SWNT-based IR detector is illustrated in Figure 1. It consists of a pair of electrodes bridged by a single nanotube. The fabrication process starts with the electrodes, made using an optical lithography method. Next, the substrate is coated with a drop of SWNT suspension and an AC signal is applied between the two electrodes. Several SWNTs are usually trapped around the electrodes by the dielectrophoresis force acting on neutral bodies in nonuniform electric fields. Finally, the AFM-based nanorobotic manipulation system is used

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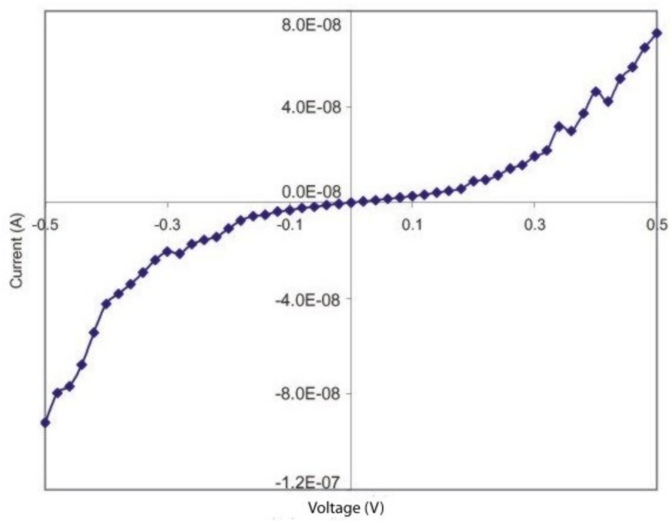

Figure 3. The I-V curve of an individual SWNT-based IR detector.

to position one CNT as a connector between the electrodes and to clean out the other CNTs. Figure 2 shows the AFM image of a SWNT-based IR detector.

Experimental results

Since a SWNT has different functionality with gold electrodes, a Schottky contact is formed at each of its ends. This allows the device to function like two reversely connected Schottky diodes. Figure 3 shows the measured I-V curve of an individual SWNT-based IR detector, which is clearly exhibiting Shottky diode behavior.

The photocurrent response under multiple on/off IR illumination cycles is shown in Figure 4. In these experiments, carried out at room temperature, the incident IR power was set at 30mW. A constant bias voltage of 50mV was also applied across the SWNT and the current was monitored. The plot shows that the current immediately increases at the onset of IR irradiation, falling back to its original value when the irradiation is switched off. Tests were also conducted to measure the dark current of the detector at different temperatures, with typical results shown in Figure 5. At the same temperature, much smaller dark currents were observed relative to other IR detector materials (data not shown).

Conclusion

The newly developed AFM nanorobotic manipulation system provides an efficient tool to fabricate SWNT-based nano IR detectors. It also has the potential of being applied to the manufacture of other nano devices and systems. Our SWNT-based nano IR detectors have excellent sensitivity, response time, and dark

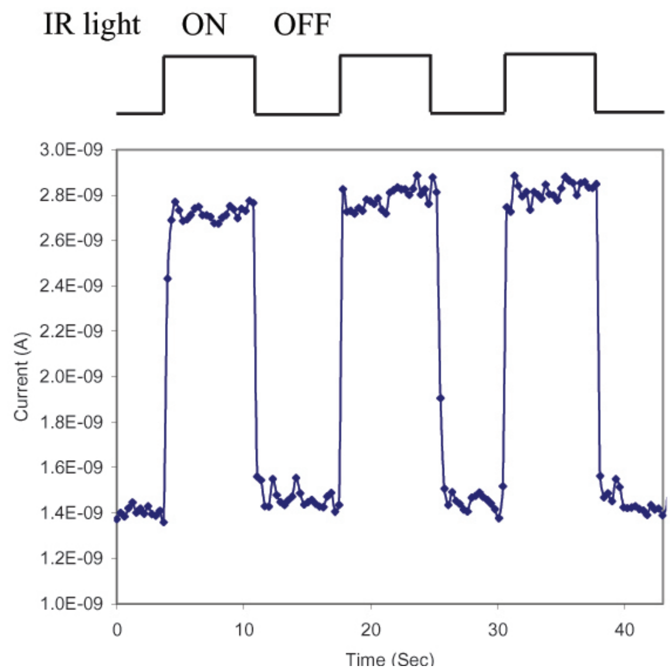

Figure 4. The Temporal photocurrent response of an individual SWNT-based IR detector.

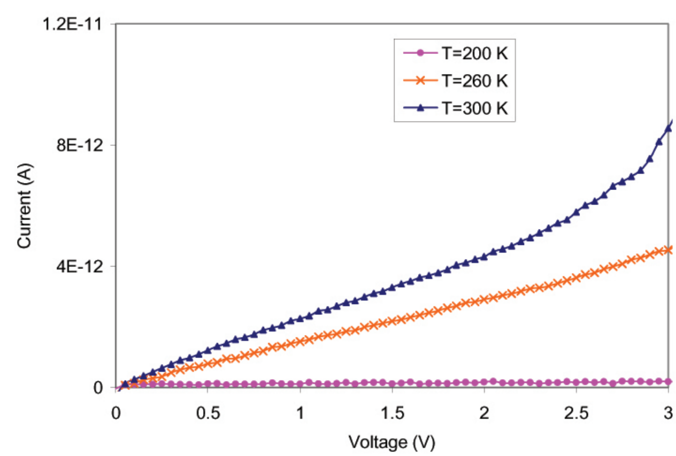

Figure 5. The I-V curve of an individual CNT-based IR detector at different temperatures.

current characteristics. Future studies will further demonstrate that the efficient use of the nano properties of CNTs can produce IR detectors with unprecedented performance.

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This research was partially supported by grant N00014-04-1-0799 from the Office of Naval Research.

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