TOWARDS SUPERSENSITIVE BOLOMETERS AND ELECTRON COOLERS BASED ON CARBON NANOTUBES

M.TARASOV, J.SVENSSON, S.DITTMER, L.KUZMIN, AND E.CAMPBELL

Chalmers University of Technology, Göteborg SE 41294, Sweden

E-mail: Mikhail.tarasov@mc2.chalmers.se

Carbon nanotubes (CNT) are being intensively developed for novel electronics. Electron cooling by superconductor-insulator-nanotube (SIN) tunnel junctions could be extremely effective due to the small volume of the CNT. A novel concept of a Cold-Electron Bolometer with a CNT as absorber should demonstrate record sensitivity due to the very low temperature that is predicted to be reached in the CNT (less than the phonon temperature). Objectives of this work is to demonstrate effective electron cooling in superconducting nanostructures comprising a Carbon Nanotube; and develop a supersensitive Cold-Electron Bolometer based on a cooled carbon nanotube as absorber.

1 Introduction

Theoretically it has been shown that electron micro-refrigeration can be effectively realized with SIN tunnel junctions [1]. Experimental results have shown electron cooling from 300 mK to 100 mK. A critical parameter is the volume or mass of the normal metal absorber. If this can be significantly reduced then the cooling effect can be expected to be increased. Carbon nanotubes are very promising new materials to allow this to be achieved. High quality single-walled carbon nanotubes (SWNT) have diameters typically in the range 1-4 nm and consist of a single sheet of graphite rolled into a cylinder. A certain fraction of produced SWNT are metallic in nature and have been shown to be ballistic conductors. Multi-walled nanotubes (MWNT) have diameters in the range up to 50 nm. It is possible to grow individual carbon nanotubes (in terms of number of nanotubes, length and diameter, SWNT or MWNT) on patterned substrates or alternatively to deposit nanotubes between metal electrodes. Typically, tunnel junctions are formed between the electrodes and the nanotubes, as required for the electron cooling application.

2 Methods and novelty

A new generation of cold-electron bolometers is planned to be developed. The method is based on direct electron cooling of the absorber to temperatures lower than the phonon temperature. For the first time the widespread hot-electron effect is replaced by a cold-electron effect with a drastic improvement of all signal and noise properties of the sensors. Implementation of CNT would bring a new level of development of these promising detectors not achieved with usual metallic nanostructures. The CNT is produced by chemical vapour deposition and plasma-enhanced chemical vapour deposition. The latter will be used to produce high quality metallic MWNT of controlled length and diameter that can then be deposited between electrodes to form the basic structure of the electron cooler. Additional electrodes are deposited on top of the nanotube using standard deep UV or e-beam lithography techniques. This method has the advantage of preferentially depositing metallic CNT. It is also possible, if necessary to deposit SWNT in this fashion. Methods are being developed that should allow the bulk separation of metallic and semi-conducting SWNT. If successful this would provide us with purely metallic nanotube samples which will greatly increase the efficiency of the fabrication method. The first method (chemical vapour deposition) will be used to grow aligned SWNT at well-defined positions on a chip. This will enable "mass-scaled" production of many structures simultaneously. This requires the refinement of the production methods and optimisation of the substrate materials and pattern geometry to obtain the most favourable conditions for the cooling application. This will be carried out in parallel with studies to attempt to control the electronic behaviour of the CVD grown SWNT (i.e. metallic or semi-conducting).

3 Chip layout and sample fabrication

We have designed and fabricated a layout and photomask compatible for both technologies. In this layout we have the lower layer made of Nb with a seed tips between which CNT is grown (see Fig. 1 with electrodes and CNT). The next step was to obtain two or four tunnel contacts to CNT. This was arranged by the next lithography step and deposition of Al thin film layer. After removing from evaporation plant the interface between Al and CNT was naturally oxidized forming a tunnel barrier. The IV curves are presented in Fig. 2. When measured in a 3-probe mode one can see two barriers, one about 2eV corresponds to Al and another about 0.5eV corresponds to CNT. Fabricated single-wall nanotubes presumably contain many defects and as a result we have high resistance and single electron tunneling mechanism with a typical Coulomb blocade features measured at temperature about 300 mK (see Fig. 3).

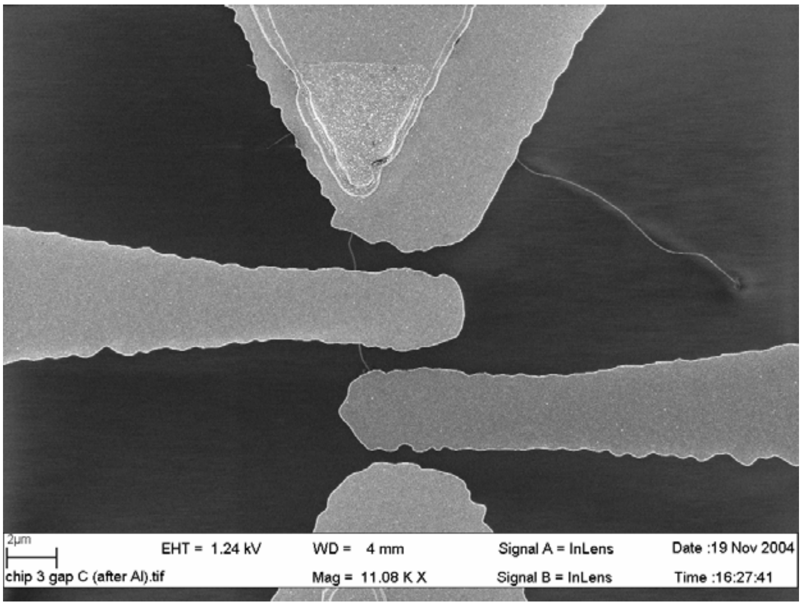

Figure 1. Two nanotubes grown on the Si substrate and covered with Al electrodes

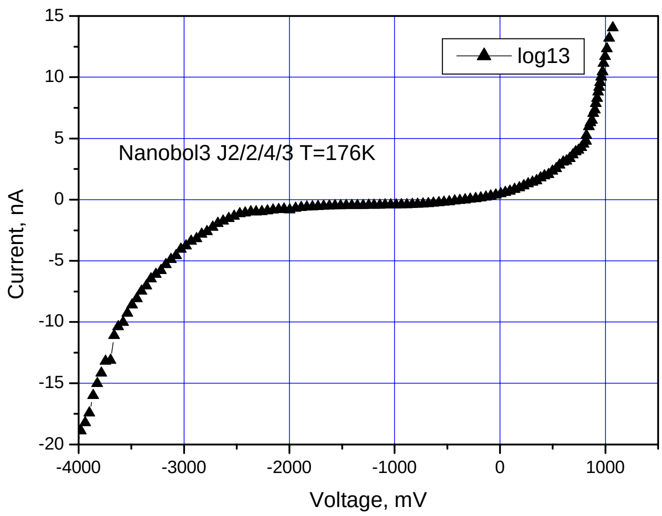

Figure 2. A 3-probe measurement of Al-AlOx-CNT tunnel junction

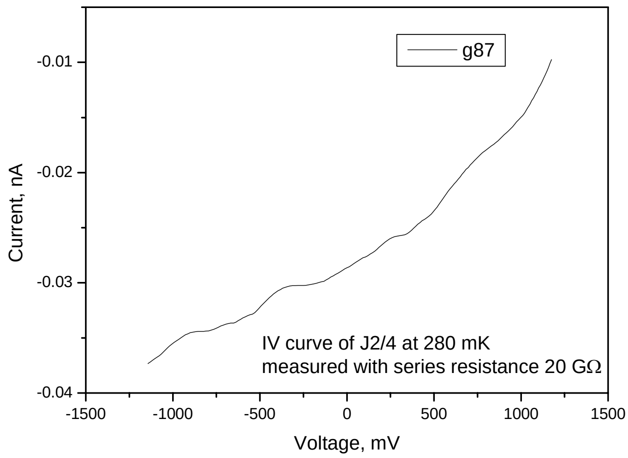

Figure 3. IV curve of nanotube at 280 mK with clear SET step structure.

4 Discussion

We have made first attempt to develop a novel device – a carbon nanotube cold electron bolometer CNTCEB. A prototype of generic layout was designed and masks were fabricated. First samples with SWCNT show that with this technique we can terminate a CNT to electrodes by SIN tunnel junctions. Resistance of a semiconducting single-wall CNT is too high for practical applications and further progress is expected with metallic multiwall CNT and ropes of such tubes.

5 Acknowledgements

This work was supported by Swedish Institute and INTAS.

References

1. L. Kuzmin, I. Devyatov, and D. Golubev. Cold-electron bolometer with electronic microrefrigeration and the general noise analysis². Proceedings of SPIE, v. 3465, The 4th International conference on mm and submm waves, San-Diego, pp. 193-199, July 1998)