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ScienceDirect
Materials Science and Engineering C 28 (2008) 299–302
MATERIALS SCIENCE & ENGINEERING C
www.elsevier.com/locate/msec

Interconnection of specific nano-objects by electron beam lithography — A controllable method

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Received 6 September 2006; accepted 31 January 2007
Available online 7 February 2007

Abstract

We report a widely applicable and highly controlled approach, based on electron beam lithography (EBL), to interconnect single nano-objects, previously immobilized onto solid surfaces, and to investigate the transport properties at the level of single nanostructures. In particular, a three-step EBL-procedure was used for this purpose by patterning two planar contacts on the sides of an individual nano-object. To demonstrate this approach, we use two different kinds of active elements: a semiconductor nanocrystal (tetrapod) and a thin triangular gold nanoprism (NT).

Keywords: Electron beam lithography; Molecular electronics; Nanotechnology

1. Introduction

The pursuit of circuit integration beyond the limits of silicon-based technology has stimulated considerable research activity in the field of molecular electronics. Whilst advances in chemical synthesis, from organics to nanocrystals, have generated a number of interesting candidate molecular structures, a major stumbling block is represented by the requirement for reliable methods to assemble real devices.

Initial investigations of charge transfer through nanostructures were performed by scanning probe techniques, namely Scanning Tunneling Microscope [1] and Conductive Probe-Atomic Force Microscope [2]. Subsequently, various approaches to interconnect and probe nano-objects (both two- and three-terminal devices) have been demonstrated. A basic device design is represented by planar metal–insulator–metal nanojunctions, consisting of two closely spaced metallic electrodes on the surface of an insulating medium. In addition to allowing in-plane transport experiments at the surface of a solid, a field-effect can be readily introduced in such devices via a gate electrode on the back surface [3].

Molecular self-assembly in mono(multi)-molecular layers or patterns has been used to implement nanodevices based on different nano-objects, such as CdSe nanocrystals [4] or benzene-1,4-dithiol molecules in planar metal–insulator–metal nanojunctions [5]. However, this approach requires a detailed knowledge of the positions and chemical properties of the functional groups to be used for immobilization, in order to develop a reasonable linkage strategy. Moreover, in experiments based on functionalized surfaces, particles are randomly deposited, and thus the probability of obtaining single/few nanostructures immobilized between the electrodes is rather low and quite difficult to control. Alternative strategies, such as electrostatic trapping (ET) [6–8] and dip-pen nanolithography [9], have been recently developed in order to achieve delivery of individual nanostructures to specific locations in a highly controlled manner. In particular, ET is a very promising technique as it allows precise positioning of a single nano-object between two metal electrodes, but some nanoscale applications remain problematic [10].

In this frame, we have developed a highly controlled approach, based on electron beam lithography, to interconnect in a

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0928-4931/$ - see front matter
doi:10.1016/j.msec.2007.01.009

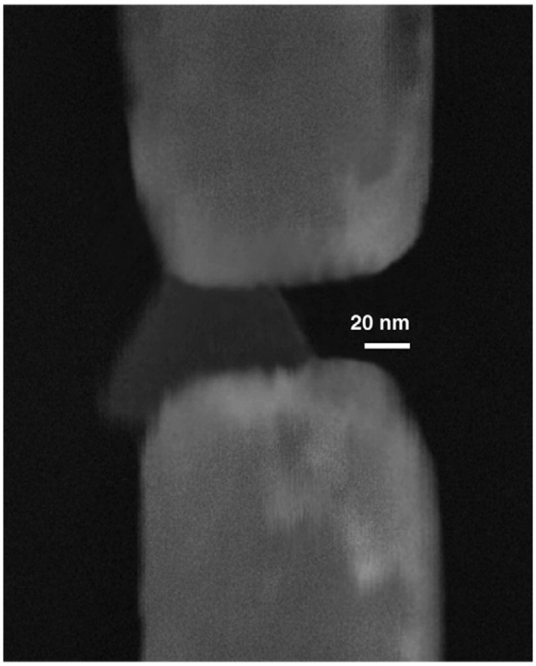

Fig. 1. High magnification plan-view SEM image of a single NT with approximate dimensions of 70 nm, trapped by the EBL alignment procedure between two nanoelectrodes with a separation of about 40 nm. Scale bar, 20 nm.

precise and reliable manner single nano-objects, and to investigate transport properties at the level of the single nanostructure.

2. Experimental, results and discussions

We demonstrate the reproducibility and wide applicability of our method by using, as active elements, two different kinds of nano-objects: semiconductor nanocrystal tetrapods and flat, thin

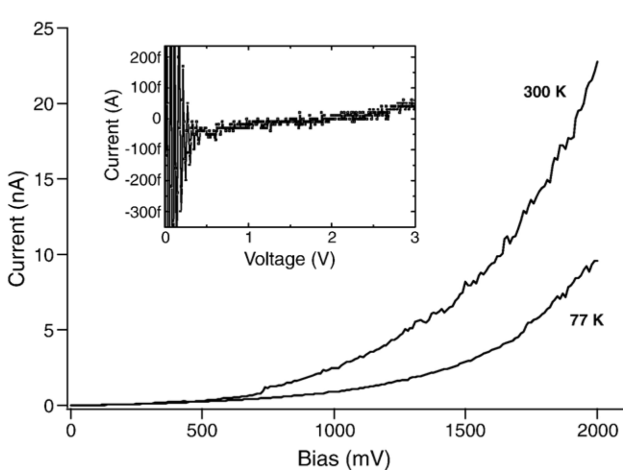

Fig. 2. Two typical I–V characteristics of a single nanoprism trapped between two gold electrodes, collected at room (300 K) and cryogenic (77 K) temperature. The inset shows the I–V characteristic at room temperature on empty device (i.e., without NTs) revealing very low current signals (less than 100 fA).

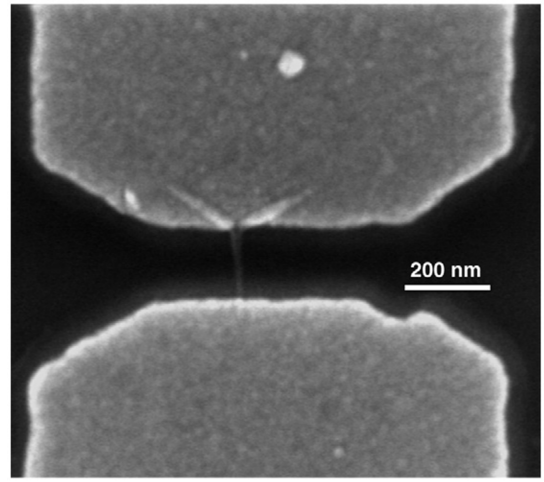

Fig. 3. SEM images of a single CdTe tetrapod with arm length of about 150 nm positioned at the electrode gap of a two terminal device by EBL process.

triangular gold nanoprisms. Tetrapods, grown by chemical synthesis, are an especially interesting class of nanocrystals due to their unique shape, where four arms branch out at tetrahedral angles from a central core (arm length: 20–200 nm, arm diameter: 5–10 nm) [11]. On the other hand, nanoprisms, prepared by biological synthesis by reacting a lemongrass plant extract with aqueous chloroaurate ions [12], have typical dimensions in the 50–600 nm range with thickness of about 15–20 nm.

The nano-objects were deposited onto SiO_2 surfaces and interconnected by a three-step EBL process consisting of: i) fabrication of four markers for alignment; ii) localization of an individual nanostructure with respect to the markers; iii) patterning of two or three contacts on the sides of the

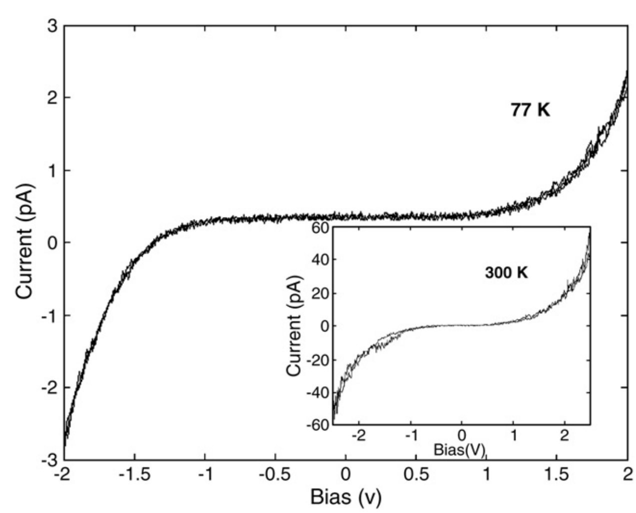

Fig. 4. Current voltage response at $T = 77$ K of a single CdTe tetrapod. The inset shows the I–V characteristic at room temperature. These measurements were performed by means of a Karl Suss probe station combined with an Agilent Parameter Analyzer, and by a Low Temperature Microprobe (MMR Technologies). Control experiments carried out on empty devices (i.e., without tetrapod) revealed very low current signals (always less than 100 fA).