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3D Nanomanipulation: Design and applications of functional nanostructured bio-materials

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Abstract. Recent progress in the development of the new functional materials opens up exciting possibilities for designing reconfigurable micro- and nano-structures and for operating mechanical nanotools which are controlled by external fields or heat. The nanotools such as nanotweezers with an active layer thickness of about several tenths of nm, and whose overall size is of the order of 1 μm can be applied to different micro- and nanoobjects. The present report gives an overview of the application of mechanical nanotools in 3D nanomanipulation of bio-nano objects such as micro biofibers DNA etc. The future prospects of mechanical bottom up nanomanipulation for biomedical technology, food technology are discussed.

1. Introduction

One of the current focus in nanotechnology is to develop nanostructures based food additives and delivery systems for supplements and nutrients. To achieve this, numerous methods are being used where they offer improved food palatability, taste and textures. For example, xanthan gum (polysaccharide) is used to improve the texture in salad dressings, chocolate milk and bakery items [1-3]. Past few years, protein based food additives have gained significant interest and it has been shown to have several applications in the food industry. These food proteins can form fibril or nanoparticle like structures by fine-tuning its conditions such as pH, types of ions, ionic strength, protein concentration and temperature [4]. The kinetics of resulting fibril or nanoparticle like structures are important parameters in impacting food stability along with other value added products. The formed polymers (i.e, nanoparticles or fibrils or aggregates) have novel physicochemical properties enabling their applications as protein-based gelling, thickening, foaming or emulsifying materials [5]. Despite the number of reported studies, a direct comparison of morphology and the mechanical properties is yet to be established for the development of new products to the food industry. In this context, nano-tweezer based 3D mechanical measurements may provide the reliable and precise stiffness values in comparison with conventional 2D AFM indentation measurements.

Currently in the field of manipulation and manufacturing at the nanoscale, there is an urgent need to develop new functional materials in order to fill the gap between the dimensions of modern MEMS and the real size of nanoobjects to be manipulated. Recently, the record for small mechanical tools based on composites with shape memory effect (SME) was created. The application of the technology of selective ion etching allowed for the creation of two-layer composite actuators, based on rapidly quenching nonmagnetic alloys with SME, such as Ti_2NiCu. These composite actuators can change their shape reversely and produce mechanical work using only "one-way" SME of the alloy [6]. The overall volume of the actuator of less than 1 μm^3 and thickness of active layer of the Ti_2NiCu alloy down to 70 nm was demonstrated [7]. These achievements of nanotechnology can be used certainly in various branches of biotechnology. The new technique can open the way to develop the tools for manipulation of animate or inanimate biological objects of submicron and nanometer sizes; for example, bacteria, viruses, biological particles of different nature. The first objective of this paper is to describe the 3D technology of the manipulation by nanotweezers. The second objective is to describe the application of the technology to the real nano-objects: mosquito's sensillas and DNA.

2. Composite nanotweezers design

In [9], a new scheme of composite functional material based on an alloy with a shape memory effect (SME) was proposed and experimentally tested. Recently, a composite nanomechanical tool consisting of a layer of material with a SME and an elastic layer was created and tested using the scheme of a focused ion beam (FIB) in [10–14]. Figures 1 and 2 show images in a SEM of the nano-tweezers in the open and closed position.

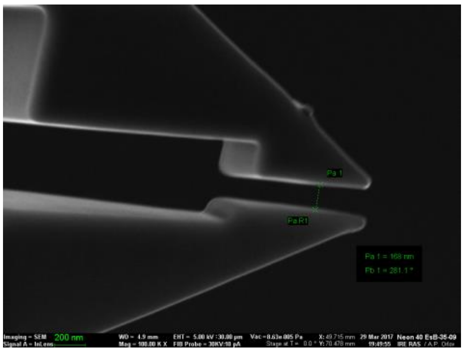

Fig. 1. SEM-image of the nanotweezers in cold position (open).

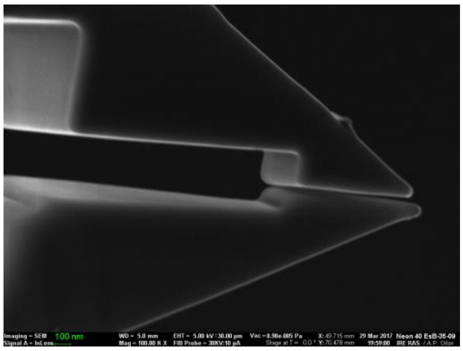

Fig. 2. SEM-image of the nanotweezers in hot position (close).

3. Composite nanotweezers application.

In the present work, a brief review of further work on improving the technology of manufacturing nanotweezers with the SME and developing the technology of mechanical nanomanipulation and nanoassembly with help of the nanotweezers is given [13]. In particular, three-dimensional manipulation of bio-objects (Fig. 3 – 4), nanocrystals, nanowires (whiskers) and carbon nanotubes (CNTs) was demonstrated, the place of nanotweezers to the object and its capture (Fig. 5), transfer and placement of the object in a specific area on the substrate (Fig. 6) are shown. The two phases of capturing DNA bunch by composite nanotweezers is shown on Fig. 7. Fig. 8 shows the finished nanostructure with contact pads for studying the transport properties of the charge density wave (CDW) in an ultrathin (78 nm wide) quasi-one-dimensional NbS_3 conductor [12]. Fig. 9 shows a similar nanostructure based on InP single crystals with four working contacts for studying the field effect and creating a prototype of field-effect transistor with a lower gate electrode. Using the method of manipulation using nanotweezers, a nanostructure of a single CNT with a diameter of 27 nm with sputtered ohmic contacts to study the transport properties and field effect was formed on a substrate with a SiO_2 (300nm) / Si bottom gate to study the transport properties and field effect (Fig. 10).

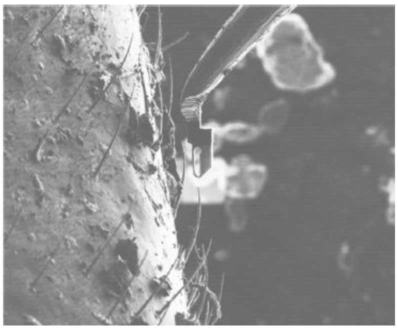

Fig. 3. Placing of the nanotweezers near the body of *Culex pipiens* and selection of the fiber on it.

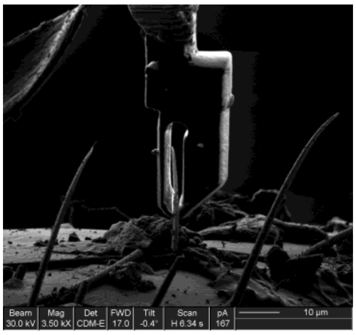

Fig.4. Capture of a biomicro object, a sensillum of *Culex pipiens*, by T_2NiCu composite nanotweezers with SME.

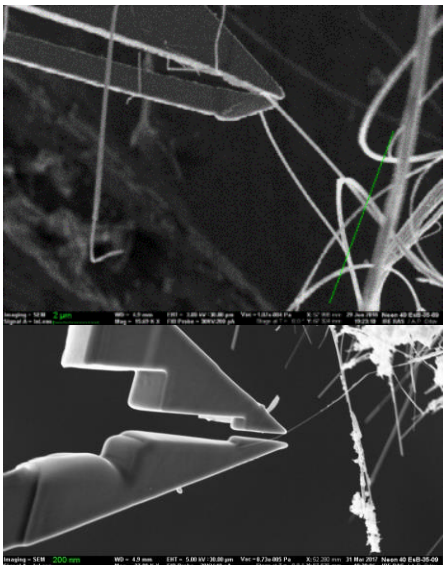

Fig. 5. Capture by nanotweezers of a single nanoobject (nano-whisker, CNT)

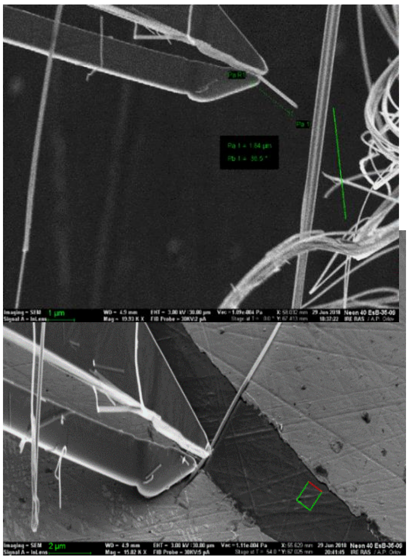

Fig. 6. Separation and assembly of a single nanoobject between contact pads

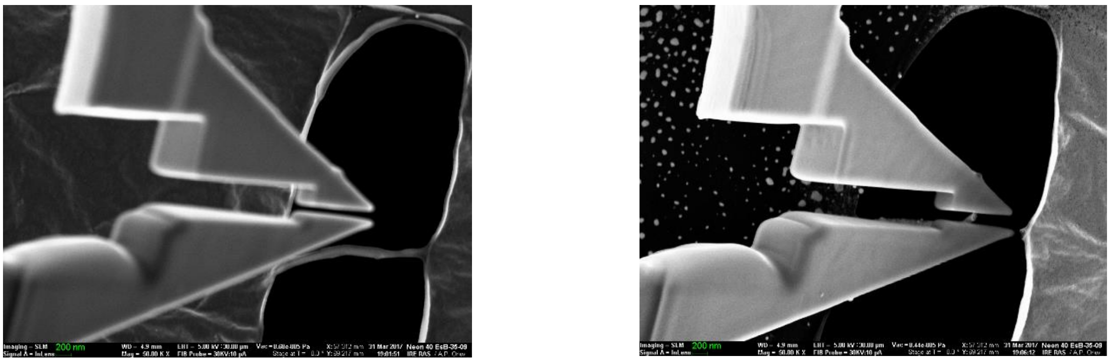

Fig. 7. Two phases of capturing DNA bunch by composite nanotweezers

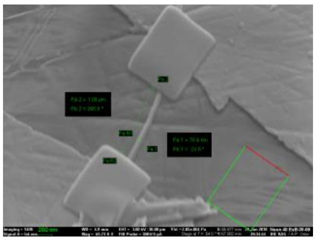
Fig. 8. Nanostructure based on NbS_3 nanowires with CDW.

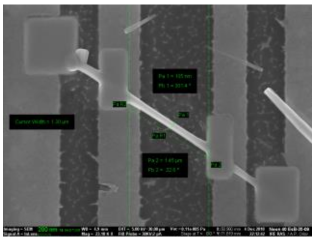
Fig. 9. Nanostructure based on the single-crystal InP

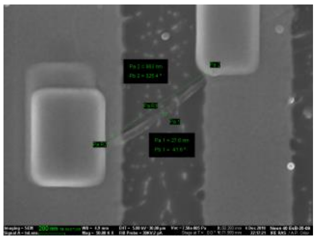
Fig. 10. Nanostructure based on the single CNT.

Thus, the work demonstrated a review of the new technology of mechanical nanomanipulation and bottom-up nanoassembling with the help of nano-tools with SME, which opens up possibilities for creating new devices for nanoelectronics, medicine and food industry.

Acknowledgment
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