Nanorobotic systems for nanomanipulation and nanopositioning

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Nanorobotics is currently a much studied field by the international scientific world. Numerous applications of nanorobotics make it to expand in several areas. This occurs through the integration of several disciplines, including nanofabrication processes used to produce nanorobots, nanoactuators, nano-sensors and nanometer scale physical modeling. Some of the most important applications of nanorobotics are nanopositioning and nanomanipulation. These, in turn, find many other applications to produce different MEMS/NEMS systems, in materials science, biomedical sciences, engineering sciences, etc. Taking into account the importance of this field, we wrote this review in order to present a part of actual nanorobotic systems technology.

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1. Introduction

On the nano scale basis, technology / micro-nanotechnology has shifted to a more powerful and intelligent control of material structure, suggesting the feasibility of achieving by the control of the molecular structure of matter atom by atom. Nanorobotics deals with the study of nanometer scale robotics and include robots that are nanometer-size and large robots able to manipulate objects with nanometer dimensions.

Nanorobotics field integrates together various disciplines, including nanofabrication processes used to produce nanorobots, nanoactuators, nanosensors and nanometer scale physical modeling. Nanorobotics manipulation technologies, including nano-scale assembly of units, biological cells and molecules manipulation and types of robots used to perform these tasks also form a part of nanorobotics (Sun et al. 2001). With the ability to position and orient nanoscale objects, nanorobotic manipulation is a promising way to enable the assembly of nanosystems. Nanorobotic manipulation systems can be used for nanoassembly, biotechnology, construction and characterization of nanoelectromechanical systems (NEMS).

2. Manipulation methods

The most common ways to achieve nanometer scale setting in motion are the electrostatic, electromagnetic, piezoelectric and thermal. For nanorobotic manipulation besides nano-resolution and compact sizes, the actuators, generating large movements and forces, are the most suitable for such applications.

Speed criteria are less important as long as the speed of movement is in a few Hertz domain and more. Table 1 provides a small selection of researches regarding suitable actuators for the principle of movement in order to be used for nanorobotics applications (T. Ebefors 2002).

Table 1. Actuation with MEMS.

Actuation principle	Electrostatic	Magnetic	Piezoelectric	Thermal
Type of motion	Linear	Linear	Linear	Linear
Volume (mm^3)	400	0.4×0.4×0.5	25.4×12.7×1.6	0.3×0.3×0.4
Speed (s^{-1})	5000	1000	4000	2000
Force (N)	1×10^{-7}	2.6×10^{-6}	350	4.4×10^{-6}
Stroke (m)	6×10^{-6}	1×10^{-4}	1×10-3	2.5×10^{-6}
Resolution (m)	NA	NA	7×10^{-8}	NA
Power density (W/m^3)	200	3000	NA	NA
Load (N/m)	1×10^{-8}	6.5×10^{-3}	1×10^{-4}	15×10^{-6}
Frequency	45	20	40	30
Actuation principle	Electrostatic	Magnetic	Piezoelectric	Thermal
Type of motion	Rotational	Rotational	Rotational	Rotational
Volume (mm^3)	$\pi/4\times0.5^2\times3$	2×3.7×0.5	$\pi/4\times1.5^2\times0.5$	$1\times1.5\times1.5^2$
Speed (s^{-1})	40	150	30	70
Torque (Nm)	2×10^{-7}	1×10^{-6}	2×10^{-11}	1.6×10^{-6}
Stroke (m)	2π	2π	0.7	NA
Resolution (m)	NA	$5/36\pi$	NA	NA
Power density (W/m^3)	900	3000	NA	NA
Load (N/m)	1×10^{-6}	1×10^{-7}	1×10^{-11}	1×10^{-6}
Frequency	10	65	10	35

Electrostatic charge is based on the accumulation of free electrons in a material, which can exert an attractive force on opposite charged objects or a repulsive force on similar charged objects. Because electrostatic fields appear and disappear quickly, such devices will have high operating speeds and will not be influenced by ambient temperature. Electrostatic fields can exert large forces, but

Table 2. Specifications of MM3A.

Item	Specification
Operating range q_1 and q_2	240°
Operating range Z	12 mm
Resolution A (horizonal)	10^{-7} rad (5 nm)
Resolution B (verical)	10^{-7} rad (3.5 nm)
Resolution C (linear)	0.25 nm
Fine (scan) range A	20 µm
Fine (scan) range B	15 µm
Fine (scan) range C	1 µm
Speed A, B	10 mm/s
Speed C	2 mm/s

Calculations show that, when scanning in the A / B direction by q_1/q_2 connection, additional linear motion in C is very small.

A nanorobotic manipulation system with 16 degrees of freedom (DOFs) is shown in Fig. 3a, which can be equipped with three or four AFM peaks as effectors both for manipulation and measurement. System specifications are presented in Table 3. Functions of nanorobotic manipulation system for nanomanipulation, nanoinstrumentation, nano-fabrication (Dong et al. 350) and nanoassembly are presented in Table 4. Measurements of four semiconductor samples are probably the most complex manipulation that can perform this system because it is necessary to stimulate four independent samples by four manipulators. Thus, three manipulators can be used to assemble a nanotube transistor, a third sample can be applied to cut a tube placed on other two samples, four samples can be used for measurements with four-terminals to characterize the electrical properties of a nanotube or a junction with nanotube. If all four samples are used together, many and various applications are possible for manipulators.

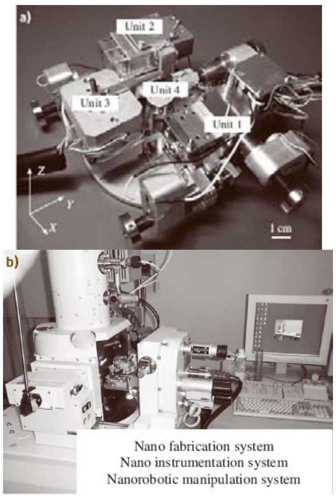


Fig. 3. a, b. Nanorobotic system. (a) Nanorobotic manipulators. (b) System set-up.

A nano laboratory is shown in Fig. 3b and its specifications are in Table 3. The nano laboratory integrates a nanorobotic system for nanomanipulation with an analytical system and a nanofabrication system. It is a complex system, taking into account that it can be applied for nanomaterials manipulation, nano-groups manufacturing, nanodevices assembling and in situ properties analysis of such materials, groups and devices.

Table 3. Specifications of nanorobotic nanomanipulation system.

Item	Specification
Nanorobotic manipulation system	
DOFs	Total: 16 DOFs
	Unit 1: 3 DOFs (x, y and β; coarse)
	Unit 2: 1 DOF (z, coarse), 3-DOF (x, y and z; fine)
	Unit 3: 6 DOFs (x, y, z, α, β, γ; ultrafine)
Actuators	4 Picomotors (Units 1&2)
	9 PZTs (Units 2&3)
	7 Nanomotors (Units 2&4)
End-effectors	3 AFM cantilevers + 1 substrate or 4 AFM cantilevers
Working space	18 mm × 18 mm × 12 mm × 360° (coarse, fine), 26 µm × 22 µm × 35 µm (ultrafine)
Positioning resolution	30 nm (coarse), 2mrad (coarse), 2 nm (fine), sub-nm (ultrafine)
Sensing system	FESEM (imaging resolution: nm) and AFM cantilevers
Nanoinstrumentation system	
FESEM	Imaging resolution: 1.5 nm
AFM cantilever	Stiffness constant: 0.03 nN/nm
Nanofabrication system	
EBID	FESEM emitter: T-FE
	CNT emitter

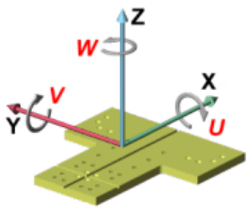
Table 4. Functions of a nanorobotic nanomanipulation system.

Functions	Manipulations involved
Nanomanipulation	Picking up nanotubes by controlling intermolecular and surface forces, and positioning them together in 3-D space
Nanoinstrumentation	Mechanical properties: building and stretching
	Electrical properties: placing between two probes (electrodes)
Nanofabrication	EBID with a CNT emitter and parallel EBID
	Destructive fabrication: breaking
	Shape modification: deforming by bending and buckling and fixing with EBID
Nanoassembly	Connecting with van der Waals
	Soldering with EBID
	Bonding through mechano-chemical synthesis

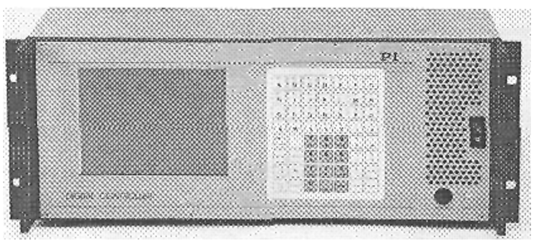
4. Technology of INCDMTM

By separating the image making and manipulating functions, nanorobotic nanomanipulators may have more degrees of freedom including rotation for control of orientation and thus, can be used to manipulate 0D objects (spherically symmetric) to 3D objects in space (Gheorghe I. Gh. 2010a).

A Hexapod positioning system for Micro-Movement F-206 (Fig. 4), produced by Physics Instruments (PI) GmbH & Co. KG, Karlsruhe, Germany is integrated at INCDMTM, within MEMS / NEMS laboratory (Gheorghe et al. 2010b). 6-axis positioning system F-206 consists of an attachment position system (Fig. 4a) and a control unit (Fig. 4b). A keyboard and a monitor for the control unit (either included or connected as a peripheral device) may be used to control F-206 system directly or, typically, the control unit can be controlled by a PC. System's mechanics uses a parallel - cinematic positioning system. The mechanical system contains 6 linear actuators with screw actuators and optical encryption systems. The system provides 6 degrees of freedom and a minimal increase of movement of 0.1 µm. Workspace boundaries are not parallel to the axes, but they cannot overcome a rectangular solid which is given by the limits of movement X, Y and Z. The control unit is equipped with integrated software to define a pivot point anywhere inside or outside workspace of F-206 system. Rotation around this pivot point may be ordered for any combination of the 3 rotation axes. Digital command system processes complex positioning and elements of movement, including scanning procedures and alignments using optical or analog response signals from more than 2 meters.



(a)

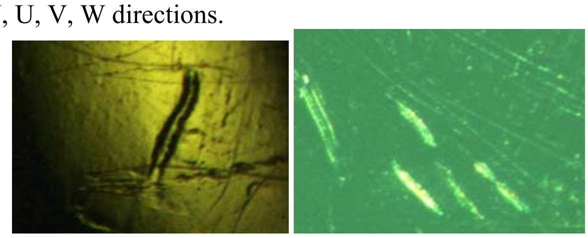


(b)

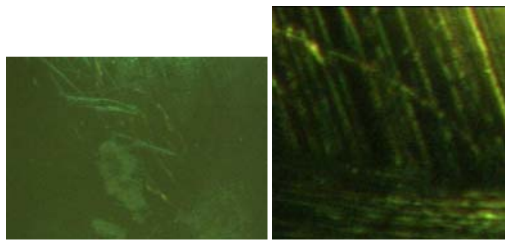
Fig. 4. (a) Hexapod positioning system – all commands and operations are using (X,Y,Z and U,V,W) coordinates. Travel range: X = -8 to +5.7 mm, Y = ±5.7 mm, Z = ±6.7 mm, U = ±5.7°, V = ±6.6°, W = ±5.5° ; (b) control unit.

All orders for "F-206 platform" positioning are given in orthogonal coordinates and converted by command system in F-206 specific actuator positions and speeds before making the action.

This system is currently used for positioning the samples studied with an atomic force microscope (Gheorghe et al. 2009). The connection between these two systems is done with a finger device that allows nanopositioning of samples used. Few results obtained with this device are presented in Fig. 5. In this figure are presented the images obtained using the device F-206 alignment and positioning system with six axes – atomic force microscope. These measurements have been used to characterize and to determine the roughness of femoral head surfaces from a hip prosthesis. Our device helped us to position the femoral head in such a way to make these measurements on different parts of it. It was moved on X, Y, U, V, W directions.



(a) (b)



(c) (d)

Fig. 5. Images obtained with the device Hexapod system for Micro-Movement F-206 - AFM. Images of cutting (a), scratches (b, d) and particle (c) on Co-Cr femoral head of a hip prosthesis (MEMS/NEMS Laboratory, INCDMTM)

5. Nanomanipulation and nanopositioning applications

One of the most important applications of nanorobotic nanomanipulation is nanorobotic assembly. Self-assembly is required when starting from atoms; groups of molecules can self-assemble rapidly because of their thermal motion, allowing them to explore the environment and finding complementary molecules (G. M. Whitesides et al. 2002).

Nanorobotics provides new techniques for exploring the bio field by manipulation and characterization of nanoscopic objects as cell membranes, DNA and other biomolecules.

Materials science, biotechnology, electronics and mechanical stimulation will benefit from nanorobotics developments. Research topics in biorobotics include autonomous manipulation of cells or molecules, characterization of mechanical properties of biomembranes using nanorobotic systems with integrated vision and force sensing modules. The objective is to obtain a fundamental understanding of uni-cellular biological systems and studies of wrong cells. Because of