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Selected manufacturing techniques of nanomaterials

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Materials

ABSTRACT

Purpose: Enabling nanofabrication techniques as tools for experiments to understand the underlying science and engineering in the nanometer scale are required. This paper is a resume a range of technology and characterization tools relevant for nanoeletronics devices.

Design/methodology/approach: An overview on bottom – up and bottom – down fabrication techniques are presented in this paper. As an alternative to the continually increasing cost of nanotechnology for manufacturing electronic devices, new strategies are examined in research, which are based on basic principles of physics and chemistry. For example, molecular self-organization mechanisms are developed in order to manufacture well-defined nanostructures with desired properties.

Findings: This paper includes description of three methods of production nanolayers and monolayers molecular self-organization, Langmuir – Blodget films and Nanoimprint Lithography.

Research limitations/implications: The most extreme approach is to build nanostructures atom by atom with the help of scanning tunneling microscope at low temperatures. This is very slow method to build nanostructures, usually a couple of hours. An alternative approach for the formation of nanostructures is self – organization of atoms.

Practical implications: The greatest advantage of litographic patterning is very large variety of different structures which can be defined by lithographic methods, Langmuir – Blodget (LB) films is another unpopular method to produce nanomaterials.

Originality/value: Materials engineering technology stands today at the edge of a huge challenge: produce cheap nanomaterials for nanoelectronics. Building materials from the bottom up requires a multidisciplinary approach. This arena is unquestionably in the nano-dimension, where all fields of science and engineering meet.

Keywords: Nanomaterials; Thin&thick coatings; Manufacturing techniques of nanomaterials; Self – organization

1. Introduction

Designed materials and new tools hold the key for future science and technologies. Building materials from the bottom up is complementary to traditional top-down materials processing, but requires a deep understanding of the individual molecular structures, their assemblies, and dynamic behaviors [1, 2].

The performance of materials engineering depends on their properties. The properties in turn depend on the atomic structure, composition, microstructure, defects and interfaces, which are controlled by thermodynamics and kinetics of the synthesis. Progress in nanotechnology depends upon the capability to produce nanostructure in a variety of materials in the nanometer scale. It appears that different demanding conditions are needed for developments in optics, sensors and biological applications. Enabling nanofabrication techniques as tools for experiments to understand the underlying science and engineering in the nanometer scale are required.

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Characteristic phenomena for structures of a few nanometers in size a the very few charge carriers, the relevance of single dopant atom, the large surface to volume ratio and high electric fields across small structures.

Nanoelectronic is emerging as a new field geared to continuously alter or replace the present microelectronics. The embodiment of new device concept rests on two approaches fabricating structures beyond the 20 nm regime [3, 4].

One is more expensive "top down" approach based on lithography, and the second is the "bottom up" approach which is based on the nanometer scale building blocks such a nanoparticle, nanocrystals, nanotube, nanowires. Great efforts are undertaking to advance techniques e.g. self assembly, advanced lithography, transmission electron microscopy, for the fabrication and characterization of nanometer –scale structure [2].

It seems to be a requiarement a resume a range of technology and characterization tools relevant for nanoeletronics devices. An overview on bottom – up and bottom – down fabrication techniques are presented in this paper, including scanning probe manipulation techniques, atomic layer deposition and the formation of nanostructured by various self – assembly concept. Classification of techniques to produce nanomaterials depends on whether the nature of the pattering is chemical or physical or the process is parallel or sequential in time [1,2 5-7].

The most popular methods used to obtain nanocrystalline materials are: PVD – techniques and CVD. These techniques are very versatile and suitable for the deposition semiconductors, electronic and optoelectronic device materials and materials for optical and corrosion application. Coatings can be produce from 100 µm to a thickness on the atomic layer scale.

Relatively large (equal 100nm) structures could be created by lithography. The greatest advantage of litographic patterning is very large variety of different structures which can be defined by lithographic methods. The most extreme approach is to build nanostructures atom by atom with the help of scanning tunneling microscope at low temperatures. This is very slow method to build nanostructures, usually a couple of hours. An alternative approach for the formation of nanostructures is self – organization of atoms. Initially disordered atoms tend to form nanoclusters or nanowires at a surface, under certain conditions [1, 2, 6].

The scanning tunneling microscope (STM) was initially intended for imaging surface. It was observed that the tip influences the surface and this obvious disadvantage for imaging was readily turned into a positive prospect. Studies showed that STM indeed offers possibilities to modify surface down to the nanometric scale or even to the atomic scale.

Building materials from the bottom up requires a multidisciplinary approach. This arena is unquestionably in the nano-dimension, where all fields of science and engineering meet. New ideas and collaborations will be fostered when scientists from diverse background collaborate.

2. Fabrication techniques to produce nanomaterials

2.1. Application of Nanoimprint Lithography

The nanoimprint lithography (NIL) perhaps it is the most developed of the alternative nanofabrication techniques. Three basic components are required to nanoimprint a surface :

- a stamp with suitable feature sizes,
- a material to be printed,
- and equipment for printing with adequate control of temperature (90˚C to 100˚C above T_g in a scale of time of few minutes), pressure (in the range of about 50 to 100 bar) and control of pararelizm of the stamp and substrate, see Fig.1.

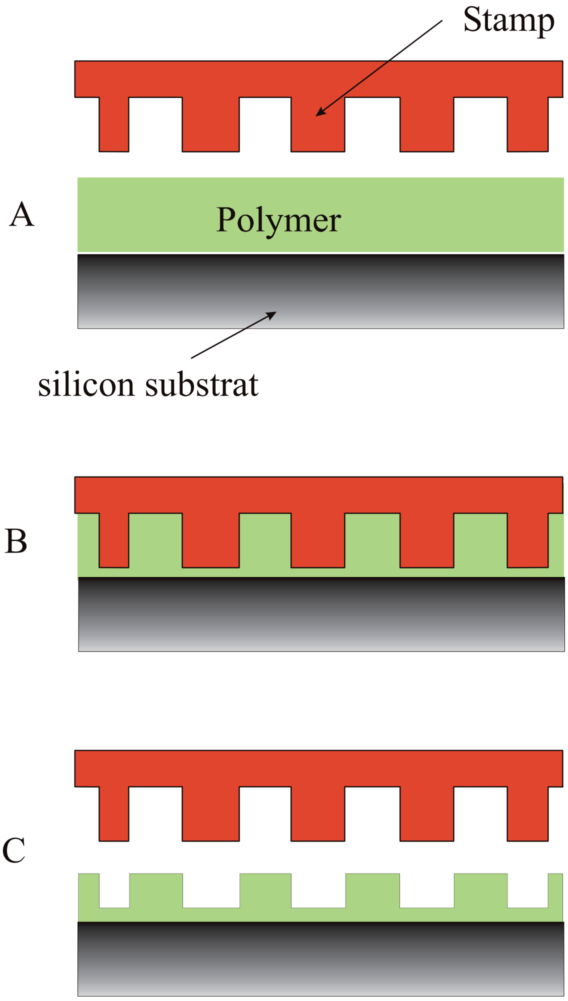

Fig. 1. Schematic of the principles of Nanoimprint lithography. The heat sample and stamp (A), bring stamp and sample into contact and apply pressure (B), cool down and separate from the sample [2]

NIL is a flexible, low cost and biocompatible fabrication technique. Therefore NIL has the advantage over conventional nanofabrication technique and there have elaborated several variations. One of the approach in which no pressure is applied and instead a UV polymer curing process enters in the sequence – it is called step and flash imprinting lithography (SFIL)

NIL is fabrication approach for organic opto – electronic and sensors. This techniques is used to fabricate organic light emitting diodes by pattering gratings of 400nm on a conjugated polymer to a depth of 20 nm. Another example of the application is a data storage, bioelectronics and nanofluids [2, 8-10].

2.2. Controllable organizations of one, two and three dimensional self assembly nanomaterials

Important request concerning the use of nanoparticles in microelectronic devices or sensors interface is the possibility of an easy and cheap controllable organization of nanoparticles.

A self-organizations of atoms is an alternative approach for the formation of small nanostructures. Under certain condition initially disorder atoms tend to form nanostructured clusters, crystallites or wires. We can distinguish four different kinds of self – organization of nanostructured at surfaces:

- nanostructures formed during molecular beam epitaxy (kinetically self – organization)
- formation of thermodynamically stable nanostructures
- formation of nanostructures by nucleation of islands at defect sites at the surface.
- combinations of self – organization and lithography methods (hybrid methods)

There are many applications for nanomaterials obtained by using those methods. For example single electron transistor (SET) based on Au – nanoparticles.

Unfortunately not all step of production procedure could be controlled in detail. Therefore a number of the gap bridging nanoparticles varied in different devices [2, 11-13].

Another large research area of electronic nanodevices is gassensors and biosensor. Traditional gas sensing devices base on semiconductor metal oxides. Metal oxides are cheap and easy to syntesis or modification by doping with noble metal

The use of nanpoparticles for the creation of sensing interfaces based on noble metal or semiconductor nanoparticles is a promising prospect. Exposed surface volume is the most important parameter characterize a performance of sensor devices. Sensor device based on nano-sized materials enable enhanced sensitivity, further miniaturization, varying the composite.

A disadvantage of the use of self-organization for the formation of nanostructures is that the only very simple kinds of nanostructures can be build [2, 11-15, 17].

2.3. Potential application of Langmuir - Blodgett Films

The principle of all techniques to produce Langmuir – Blodget (LB) films is an amphiphilicity of the molecules forming a monolayer on a water surface. Amphiphilic molecues consist of a headgroup which is easly soluble in water (hydrophilic) and a long alkyl chain which is insoluble in water (hydrophobic).

To create a molecular monolayer an a substrate the surface layer has to be transferred to a solid surface. This is most commonly done by lowering the substrate through the monolayer into the subfase and then withdraws.

The cycle of lowering and withdrawal of the substrate can be repeat so that a mutilayer is formed. There is some maximum speed for withdrawal of the substrate in order to get a complete film without ruptures. Typical maximum speeds resulting are 10µm/s to a few mm/s for the initial layer. For the following layers withdrawal can be done faster [1,2].

It has been shown that the friction and the rate of wear are reduced by orders of magnitude by only a single monolayer. An application for magnetic tapes has proven successful but was not commercialized because of the high cost of coatings.

Another area where LB coatings may be used is the glass panes of liquid crystals displays (LCD). The photoresist coatings with higher resolution is another potential application of LB coatings. There has been some effort to construct chemical and biological sensors (for example glucose sensor) using LB films which give an electrical output proportional to the concentration of a substance [1,2, 16-19].

3. Conclusions

Future progress in electronics will be determined by developing of more productive and compact integrated circuits and nanometer – size devices with reasonably acceptable costs. One way of advancement in electronic nanomanufacturing is based on developments in lithography and semiconductor miniaturized processing techniques. In the other synthetic (bottom-up) approach the functional elements are proposed to be formed starting with atoms and molecules via cost – effective nanoscale- controlled assembly and self-organization processes.

Preparation of nanosized materials has received a lot of attention in present-day research, as they have potential in the fields of electronics, optical devices, and sensors. Nanosized materials exhibit electronic and optical properties different from similar chemical composition bulk materials because of quantum size effects [2 – 4].

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