Survey of Nanoassembly

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ABSTRACT: Nanoassembly is a new field that deals with the controlled manipulation, handling and assembly of atoms, molecules and nano-objects by robots for manufacturing of nanostructures, devices and systems. Nanoassembly is expected to have revolutionary applications in almost all the scientific and technological areas. This paper presents a general review of nanoassembly considering its current developments and application. It discusses several method of nanoassembly technology and in detail self-assembly, object-oriented nanoassembly and hybrid nanoassembly.

1 INTRODUCTION

Nanoassembly is concerned with techniques and systems to organise atoms, molecules and nano-objects for building nanopatterns or nanostructures in development and fabrication of nano-materials, nanocomponents, nanodevices and nanosystems. Nanoassembly is recognised as one of the key disciplines in nanotechnology since the essence of nanotechnology is the ability to work at molecular level, atom by atom, to create large structures with fundamentally new molecular organisation. There are many nanoassembly techniques that have been developed in the last two decades and they are generally identified by their chemical, biological and physical natures such as self-assembly, object-oriented nanoassembly and hybrid nanoassembly. The invention of the scanning tunnelling microscope (STM) was the first step along the road to technologies able to act at the level of individual atoms, which allows scientists to view and manipulate atoms directly. Nanoassembly is very important in nanotechnology because manipulating arrangements between atoms, or molecules to form nanomaterials, nanodevices, and nanosystems with unique physical, chemical and biological properties opens the door to applications which mark the beginning of a truly innovative technological era. In recent years, research interest in robotic nanoassembly has been growing and some progress has been made. However, a major obstacle facing robotic nanotechnology today is still the lack of effective techniques for assembling the nanoscale structures needed in many applications.
2 SELF-ASSEMBLY

Self-assembly is a natural phenomenon that can be observed in many chemical and biological processes. This technique has the advantage of low cost and easy assembly of atoms and molecules into nanostructures. The main disadvantage of self-nanoassembly is that it cannot produce designed and interconnected patterns or structures.

Self-assembly can be considered as a new strategy for nano and microfabrication that involves designing molecules and supramolecular entities so that shape-complementarity causes them to aggregate into desired structures. It draws from the enormous wealth of examples in biology for inspiration: self-assembly is one of the most important strategies used in biology for the development of complex, functional structures. Because self-assembly requires that the target structures be the thermodynamically most stable ones open to the system, it tends to produce structures that are relatively defect-free and self-healing.

Recent technological advances have led to the development of many novel “bottom-up” synthetic fabrication strategies capable of creating ordered mesoscale component arrays with a wide variety of tuneable properties.

In this context self-assembly is increasingly being exploited to assemble mesoscale objects (structure larger than the nanoscale and smaller than the millimetre scale) at the micro and nanoscale (see Figure 1). This approach also enables many of the most difficult steps in nanofabrication including those involving atomic-level modifications of structure using the very highly developed techniques of synthetic chemistry. To achieve molecular self-assembly chemists often exploit biologically inspired interaction paradigms such as shape complementarity, hydrophobic or hydrogen-bonding effects.

In order to overcome these weaknesses, automated solutions show promises. In many activities, both positional assembly and self-assembly can be found separately. However, there is little work combining both principles. In space applications, a combined approach using a hybrid course of action to develop autonomous intelligent legos to build robots has been described. In this work the robot should not only be able to recognize and change shape by itself, but can connect itself autonomously. In the field of micromanipulation, early work combining both approaches showed that small diamond seeds could be precisely placed in etched holes on a silicon substrate. These diamonds were used for epitaxially growing pure diamond nuggets. The first operation consisted of letting the diamond seeds descend in a liquid onto the surface of the silicon substrate. Shape compatibility allowed placement of more than 90% of the seeds at the right place after this first.
Figure 1. Sequential self-assembly and packaging of a three-component microsystem.

Figure 2. Schematic illustrating self assembly methods based on programmable force fields. Field assisted transport and assembly of a mesoscale device at that site.

3 OBJECT-ORIENTED ASSEMBLY

The object-oriented nanoassembly is in effect a robotic type of nanoassembly. The invention of the scanning tunnelling microscope (STM) was the first step along the road to technologies able to act at the level of individual atoms, which allows scientists to view and manipulate atoms directly.
Object-oriented nanoassembly was proposed for accurate positioning of the end-effector relative to the object in an SPM or SEM. This method uses real-time object pattern recognition to deal with the precise interactions between the end-effector of the robot and the object to be manipulated to remove the errors caused by environmental variations and instrument inaccuracy.

Fig. 3 shows a robot system for object-oriented nanoassembly. In the system, a reference pattern scale is used as a ‘ruler’.

Figure 3: A robot system for object-oriented nanoassembly.

Real-time nano imaging, pattern recognition, detection and control techniques are key to object-oriented nanoassembly. The interactions between the end-effector of the robot and the object could also be used to detect force and overload by nano force sensing and nano imaging techniques. These issues are still under investigation.

4 HYBRID NANOASSEMBLY

There are problems when applying a robot system to the manipulation, handling and assembly of nano objects, or manufacture of nano products. The first problem is the size of the robot gripper relative to that of the objects to be manipulated (the ‘fat finger’ problem). The second problem is the effect of strong adhesive forces (the ‘sticky’ problem). To address these problems, there is a need to combine mechanical, optical, electrical, magnetic and other forces
to perform nanoassembly tasks. Such a hybrid nanoassembly system or platform could become a versatile 3D nano handling or manufacturing tool.

HYDROMEL (Hybrid Ultra Precision Manufacturing Process Based on Positional- and Self-assembly for Complex Micro-Products) with twenty-four partners from universities, research institutions and companies in Europe. HYDROMEL aims to develop a new versatile 3D automated production system with a positioning accuracy of 100 nm for complex micro-devices. Based on ultra precision robots improved by the innovative knowledge-based self-assembly technology, this groundbreaking combination will participate in the massive production of high-added value strategic and emerging micro-products. This approach has never been achieved at the industrial scale and, as a consequence, is a new and flexible production concept permitting the development of a fully innovating hybrid automated tool for assembly of micro-products.

Horst Stormer, Nobel Laureate, has his vision that the combination of the top-down tools and methods with self-assembly on the atomic scale provides an impressive array of novel opportunities to mix-and-match hunks of chemistry and biology with artificially defined, person-made structures. The possibilities to create new things appear limitless.

Furthermore, there is also a need for a robotic nanoassembly system to carry out ‘top-down’ tasks such as nano lithography, cutting and electro-chemical machining. To meet these application requirements and overcome the above problems, a robotic nanoassembly system should preferably be built with hybrid system technologies. The system could combine different nano manufacturing techniques. For instance, a robotised nano manufacturing system could be a platform for the development and use of self-assembly techniques in a more precisely controlled manner. Another example might be a system equipped with different nano fabrication tools and other nano fabrication means for ‘top-down’ approaches. Hybrid nanoassembly in effect has its great potential for a wide range of nanotechnology applications in many areas such as physics, chemistry, electronics, photonics, manufacturing, bioengineering and medicine.

“New production technologies for new microdevices using ultra precision engineering techniques” as it aims to develop a new generation of versatile automated manufacturing technologies based on the combination of ultra precision automated systems and novel self-assembly (SA) methods. High performance production facilities (with regards to throughput, accuracy and innovative functionalities) for new and emerging devices from the micro- and nano-scale will arise from HYDROMEL.
A combination of positional assembly, where individual objects are mechanically manipulated and positioned, and self-assembly, where objects arrange themselves into ordered structures by physical or chemical interactions, has never been achieved. As a consequence, HYDROMEL will generate a highly innovative production concept that will dramatically change manufacturing. The hybrid technology that will result from HYDROMEL will be flexible in nature by incorporating a variety of robotic and self-assembly functionalities in order to be applicable from a manufacturing standpoint to a wide range of products. The HYDROMEL low cost and high throughput technology (at least 10 times faster than existing technologies) will fully contribute to move manufacturing “towards a new structure, which can be described as ‘innovating production’ (the so-called hybrid technology), founded on knowledge and capital (robotics, biology and chemistry). It will help adopting new attitudes towards the continued acquisition, deployment, protection and funding of a new knowledge.

Figure 4. HYDROMEL, the breakthrough combination of robotics and self-assembly for tomorrow’s micro- and nano-devices.

5 SUMMARY

The development of nanotechnology will depend on the availability of nanostructures, and the SPMs and nanotweezers have provided tools for viewing, characterising, manipulating and assembling these structures. There is no doubt that nanoassembly will have a revolutionary impact on science, technology, and the way we live. This paper has briefly reviewed the state of the art in nanoassembly. Successful developments in the areas of research discussed in this paper will unlock the full potential of the emerging field of nanoassembly and the wide range of nanotechnology applications.

REFERENCES


