Nanofabrication via Dip Pen Nanolithography™

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Keywords: nanofabrication, nanolithography, dip pen nanolithography, nanostructures, carbon nanotubes, arrays

ABSTRACT:

Dip Pen Nanolithography, DPN™, was discovered in the laboratory of Dr. Chad Mirkin at Northwestern University leading to the founding of NanoInk, Inc. The company mission is to be the worldwide leader in nanoscale manufacturing and applications development through the development of the process of DPN. This process enables researchers demonstrate the viability of building structures at the nanoscale – from the bottom-up. The DPN process is be described along with the parameters essential for reproducibility. The DPN process uses a scanning probe tip as a "pen," which is coated with molecules (the "ink") that are deposited onto a substrate (the "paper") through a controlled diffusion process. Process control is established with the first dedicated DPNWriter™ system – NSCRIPTOR™. Applications using DPN cover a multitude of different materials including organics, inorganics, biomolecules to conducting polymers and carbon nanotubes, thus finding use in the research communities from life sciences to nanoelectronics and fine chemicals. Structures have been "built" in the size range of 15nm to 100nm with as small as 5nm spacing between. Nanostructures are built by a simple three stage process: design, deposition and inspection. To make this a truly viable manufacturing process, the single pen must be replaced by arrays of pens, providing for scalability towards speed and cost reductions.

1.1 Introduction

The process of Dip Pen Nanolithography was first reported in January 1999 in *Science* by Dr Chad Mirkin of Northwestern University. This discovery has lead to the founding of NanoInk in November 2001 and the development of the technology to that provides a means of manufacturing and fabrication on the nanometer scale. In the past two years, the company has developed a range of products and capabilities to assist researchers in academia and industry develop new and exciting methods for working with materials on the nanoscale. A four-step protocol has been implemented whereby the researcher may design a structure, deposit (fabricate) it, inspect (Image with AFM) and investigate its properties within a common platform – i.e., the NSCRIPTOR system. In support of this product development effort, a large investment has been made to build a broad intellectual property portfolio to protect the fundamental technology and potential applications for the use of DPN.

DPN may be easily compared to that of using a quill pen and ink to write onto paper. Imagine the quill pen. It has a tip. To write, it is dipped in ink and may then write directly onto paper. In the case of DPN, the pen is the silicon nitride probe stylus of an atomic force microscope, a pyramidal structure with a fine tip of just 20nm. The DPN pen may be dipped into a variety of different inks where the ink may be one of many different materials: metals, small molecules, polymers, DNA and proteins to name but a few. Once inked, the tip may be brought into contact with a substrate causing the ink to bind to the surface and form a nanostructure. The substrate may also be selected from a wide range of materials. These include silicon, glass and metals, the key criteria being that they are very flat.

The writing process is governed by the rate of diffusion of the ink from the pen to the substrate. Thus, the time in contact between pen and surface, together with such environmental parameters such as temperature and humidity, will affect the size of structure being fabricated. Using this nanoscale pen, it is possible control structures in the 15nm size range, which is approximately 6000 times smaller than the width of a human hair (80 micron diameter).

1.2 Attributes of DPN

DPN offers many key advantages over existing technologies such as photolithography, e-beam lithography and microcontact printing.

Flexibility: DPN is a direct write technique requiring no photomask. It enables the user to write with both hard and soft materials in the same space, none of which are possible with the techniques noted here.

High resolution and accuracy: By using the established pick and shovel technique of the nanotechnology world, scanning probe microscopy and its main technique, atomic force microscopy (AFM), DPN has an incredibly accurate method of controlling the placement of the pen to nanoscale accuracy and to then write structure of nanometer dimensions.

Scalability: To make such a technique viable as a production tool, the methods must be fully scalable. While the initial DPNWriter was a single-pen instrument, the NSCRIPTOR products of 2004 offer multiple pen capabilities to deliver multiple inks using a variety of MEMS fabricated devices, including passive and active arrays of pen systems and associated inkwell designs to meet the increasing demands of the nano-research community.

Low cost: Unlike many "top-down" techniques, DPN uses established low-cost, technologies (SPM, MEMS, etc.) to provide customizable solutions on the nanoscale. A fundamental "bottom-up" tool, NSCRIPTOR offers a cost-effective solution to the challenge of nano-fabrication.

1.3 Applications of DPN

Through the successes of research labs publishing their uses of DPN in the last four years, DPN has seen a tremendous leap in popularity illustrated by the simple search tool on the Internet: the search engine. Employing Google just twelve months ago, you would find perhaps 200 hits under the term of dip pen Nanolithography. A search today would reveal over 2,200 hits.

As the technology has become validated through peer-reviewed publications, more interest for applying this to industrial challenges is being observed. This is because DPN allows companies to produce products that would have been impossible or cost-prohibitive to produce in the past. DPN has been applied to applications in materials discovery, semiconductors and the life sciences. DPN is becoming the tool that allows convergence between these extreme disciplines as companies search for new materials either to build nano circuits or to aid drug discovery through the investigation of combinatorial libraries of materials:

DPN may create biosensors for point-of-care diagnostics that are so sensitive and selective, they are able to lead to earlier and more accurate diagnoses of disease.

DPN has been applied in the direct-write repair of defects in flat panel displays and for photomasks in an entirely new and economical way through the development of specialized ink formulations.

DPN allows the manipulation and placement of nanotubes to create nanoscale circuitry that will offer superior performance over today's technology.

1.4 NanoInk Performance

Since formation in 2001, NanoInk has demonstrated an excellent track record. Funded through VC investment (Galway Partners and the Lurie Group), the company quickly brought products to the market place and has been generating revenues in three areas:

Software: this basic-capability software tool, to enable researchers to learn of DPN, was released in June 2002 and is distributed worldwide by Veeco for their CP-Research platform of AFM tools

Hardware: the first of the NSCRIPTOR family of DPNWriters was released in June 2003 and now has a growing user base now using multi-pen arrays and inkwell systems to demonstrate the scalability of DPN. These products are distributed through both direct and indirect sales channels worldwide.

Consumables: to support the above, NanoInk's own MEMS facility in Campbell, CA, is manufacturing inkwell systems and arrays of pens to meet the growing applications needs of the user base. This is complemented by an in-house team of chemists developing new ink formulations to match these needs.

Furthermore, the product line has been extended to provide a dedicated nanoscale testing platform called NETS™, the nanoscale experimenters test system. This enables utilization of current macroscale test and measurement systems for the measurement of properties on the micro- and nano- scales.

In step with development, a growing intellectual property platform is being established, with the first patents being granted in the US and Taiwan during 2003, and with another 70+ filings in eight jurisdictions worldwide. The company continues to aggressively develop and secure IP worldwide through both in-house and in-licensing agreements.

1.5 Concluding Remarks

NanoInk is founded upon an experienced management team with proven ability to create and commercialize breakthrough products. The technique of DPN is nothing if not such a product. As a truly disruptive technology, NanoInk's technology is emerging as a fundamental platform process for achieving true nanoscale fabrication.