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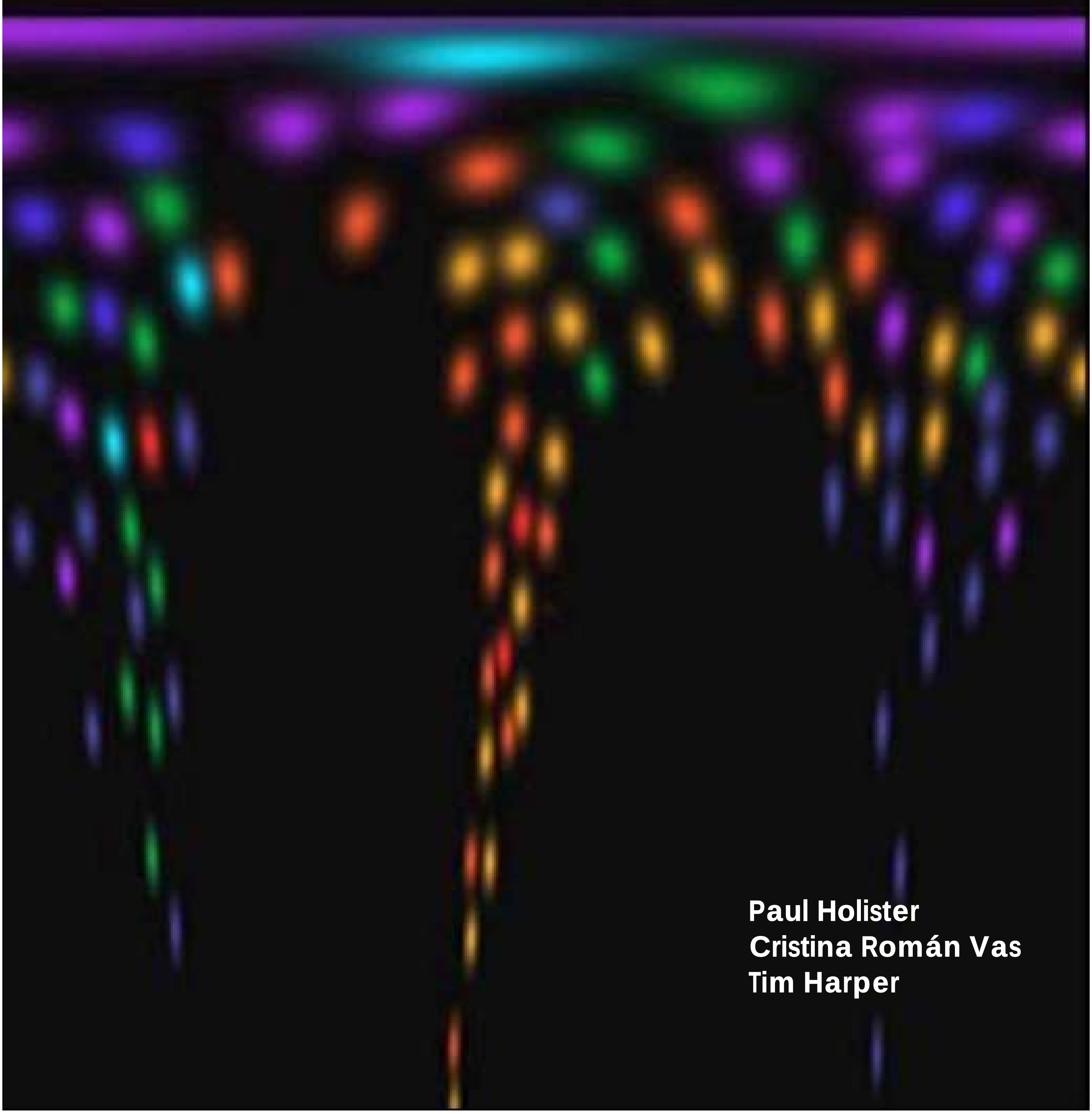
Lithography

Technology White Papers
nr. 8



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LITHOGRAPHY

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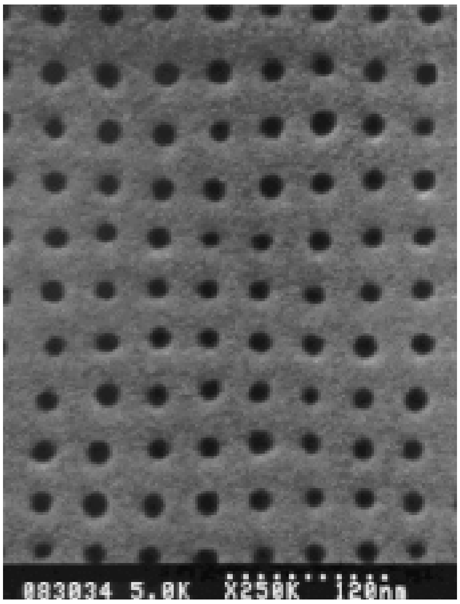
Origin of content

The free reports in this series are extracted from the technology reports that make up the Nanotechnology Opportunity Report collection and are designed to offer an introduction to the variety of technologies that fall under the nanotechnology umbrella. The full reports also include 'opportunities' sections, covering the various applications of the technology and their effects on markets, and a list describing the companies involved in the technology.

Lithography

Introduction to lithography

Resist-based approaches



SEM micrograph of a top view of 60nm deep holes imprinted into PMMA which have a 10 nm minimum diameter. Courtesy Nanostructure Laboratory, Department of Electrical Engineering, University of Minnesota.

The mask-based lithographic tools and techniques used in the traditional semiconductor industry have also entered the nano realm (sub-100 nm) and can be expected to contribute to nanotechnological development, especially in the area of nanoelectromechanical systems (NEMS) and for provision of the larger-scale supporting and connecting structures for other developments, such as molecular electronics and lab-on-a-chip systems. As an established technology they will only be briefly described here. Note that the fact that this technology is approaching fundamental limits is one of the major drivers for research into other approaches for building electronic devices.

The process behind the production of current integrated circuits involves shining light through a mask onto a photosensitive polymer (photoresist) on a silicon surface, then subsequently removing the exposed areas. The wavelength of light limits the minimum feature size obtainable by these methods and the main drive to taking this technology to 70nm feature sizes and below is focusing on using smaller wavelength electromagnetic radiation, i.e. extreme ultraviolet or X-rays, or electrons, as in electron projection lithography, which uses a scanning electron beam in place of light, but still uses the principle of a mask casting a shadow on a resist. Both these approaches are presenting formidable technical obstacles that will contribute to yet higher costs for the fabrication facilities for next-generation integrated circuits, which already run into billions of dollars.

Various tricks have been developed to improve the resolution of traditional lithographic techniques, such as off-axis illumination and optical proximity correction. One promising approach, offering potential feature sizes down to 25 nm, is the MAPPER technique being developed by Dutch start-up Mapper Lithography.

Electron beam nanolithography

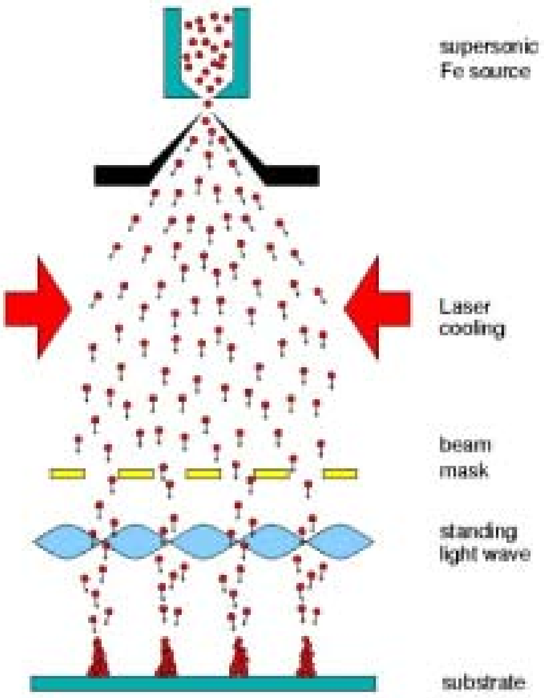
As distinct from the electron projection lithography approach that parallels existing mask-based lithographic techniques, electron beams can be used to write directly onto a substrate (a "maskless" approach), creating lines typically 30 nm in width, though 7nm lines have been produced. This approach is excellent for creating one-off nanostructures in the laboratory, and is the best-established technique for nanofabrication at the moment, but is not appropriate for mass production since each machine can only create one structure at a time (i.e. it is a serial approach) and the machines are expensive. However, the approach is certainly useful for making masters for soft lithography, which are in turn used multiple times. The machines are widely used in nanoscale research, for example for making patterned substrates upon which self-assembled structures can be made and investigated.

Recently, some groups have been looking into the use of carbon nanotubes for creating nanotube-based field emission devices that might be used for electron beam lithography and offer the parallelism required to cut costs (described under the section on nanotubes).

Ion beam nanolithography

This is similar to electron beam nanolithography in terms of applications, feature sizes and the fact that it is a serial (direct write—no mask used) approach, but uses a beam of ions instead of electrons. A fundamental difference is that ions are charged atomic matter that can interact physically and chemically with, and settle into, the exposed material, and the particles of which are many orders of magnitude more massive than electrons. This addition of material offers the possibility of building up structures rather than just creating structures destructively. Deep ion beam lithography is a new technique that can be used to produce 3D nanostructures and is particularly good at creating side walls (with almost 90 degree angles) and slopes. Thicknesses of elements in the structure can be controlled by the energy of the beam and resulting surface roughness is on the nanometer scale.

Atom lasers



Atom lithography scheme. Courtesy Roel Bosch, Atomic Collisions and Quantum Electronics Group, Eindhoven University of Technology

Developed in 1997 at MIT, the atom laser is a beam of coherent atoms, coherence in this case meaning that the atoms behave in a coordinated manner rather than just being a focused stream of particles. In mid-2001 a group at the Ludwig-Maximilians University of Munich demonstrated lenses and mirrors that could be used to focus atom lasers, opening the way to building an atom microscope. Another potential near-term use is in lithography, in which there are similarities to ion beam lithography, except that atom lasers can be made to lack the charge of ion beams. One quite fanciful application that has been suggested is the atom laser hologram, in which a solid structure, rather than an image, is created. Atom lasers may certainly one day allow the building up of layers of material at the nanoscale—compare this concept to the section on 3D printing.