Nanomachining Bridges Precision Engineering and Nanotechnology

Advances in nanotechnology enable ultra-precision machining in the optical and semiconductor industries.

by Ioan D MARINESCU

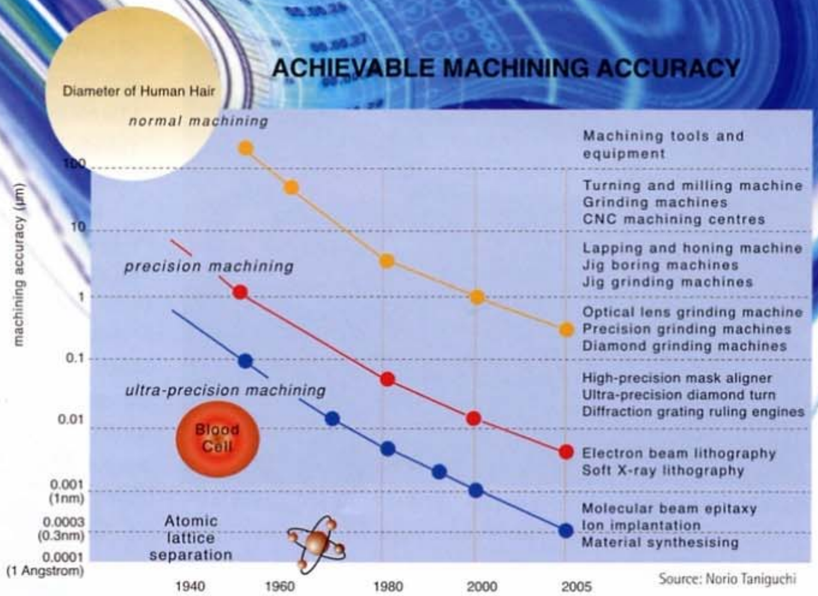
At the International Conference on Precision Engineering in 1974, Norio Taniguchi of Tokyo Science University first coined the term "nanotechnology," the study and processing of materials, devices, and systems smaller than 100nm. He used the word to describe ultra-fine machining, the processing of a material to nano-scale precision, on which he started to work in 1940 by studying – primarily via ultrasonic machining – such hard, brittle materials as quartz, silicon, and aluminium oxide ceramic.

Most people, however, would be more familiar with the now-famous line delivered in 1959 by Richard Feynman – "There is plenty of room at the bottom." Feynman predicted most of the nanotechnology methods coming from the bottom.

History reveals that two paths led towards nanomanipulation, or building things from the bottom up atom by atom: one, from the self-assembly of nano-sized particles into nanodevices and components, and two, from the use of nanomachining to achieve the same devices and components. The first bridges nanotechnology and material science whereas the second bridges nanotechnology and precision engineering.

Self-assembly is the process of atoms and molecules coming together in a self-regulated fashion, whereby specific atoms and molecules bind to one another based on their size, shape, composition, or chemical properties. For instance, a plant builds itself out of the molecules present in the air, water, and dirt – one of Mother Nature's great feats.

Nanomachining is not new. The name is neoteric, but the processes have been going on for at least 50 years – they used to be called ultra-precision machining, which began in 1940 with an accuracy of 100nm and today has attained the sub-nanometre level (Figure 1).



Source: Norio Taniguchi

Figure 1: Progress of machining over time.

Technological advances in several disciplines make possible and even stimulate nanomachining, particularly the development of ultra-precision processes, machines, and control systems that can achieve nanometre tolerances and sub-nanometre surface finishes. Some new methods include analytical techniques that can observe, measure, and provide three-dimensional images of features at nanometre and atomic levels and the ability to identify, manipulate, and assemble individual molecules and atoms. Others include advances in computer hardware and mathematical-modelling techniques that have enabled design of novel materials as well as accurately predicted their mechanical, electrical, magnetic, optical, and chemical properties.

One modern technique used to obtain nanometre and sub-nanometre surface roughness is Electrolytic In-Process Dressing (ELID) technology, which is in fact a nano-dressing process for all kinds of abrasive metal-bonded tools. Figure 2 shows ELID techniques applied to one of the grinding processes. The technology, initially developed in Japan, has spread to Europe, the US, and recently Singapore. It is mainly applied in the optical, semiconductor, ceramic, and glass industries – any time an ultra-precision machine has to machine a difficult material. When most machining methods have failed, ELID technology has come up with solutions to the problem.

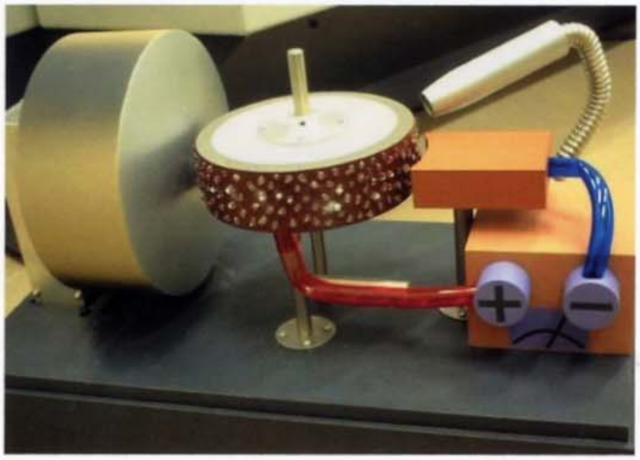


Figure 2: The principle of ELID techniques.

Another form of nanomachining is ultra-polishing aluminium titanium carbide (AlTiC) magnetic heads, an important component of today's computers. The roughness of the magnetic head (or the slider) inversely correlates to the accuracy, as well as the reliability, of the computer. A specific technology involving lapping with a special plate and diamond slurry as small as 0.125μm will lead to surface roughness as low as 0.2nm. Figure 3 represents such a surface with an embedded diamond in the AlTiC head, which represents one of the most frequently found defects, a scraped component. The process' stock-removal mechanism is not completely understood, but calculations show that it is based on the removal of layers of molecules to a relative depth of cut of under 1nm. The physics of the process is still under study even through industry has been using the technology for years.

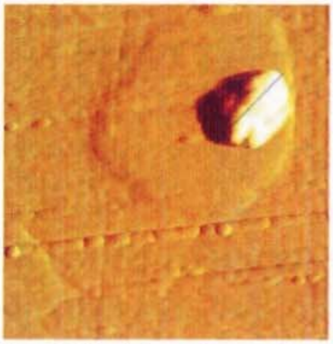


Figure 3: Atomic force microscopy image of an AlTiC surface with an embedded diamond grain.

New methodologies for modelling processes at the nanometre level, especially for both nanocutting and nanogrinding (polishing), include molecular dynamic modelling and simulation. This method relies on a calculation of the potential between the molecules of a material; potential change is related to change of the position of the molecules in the structure. Such a simulation requires a lot of computational power, usually in the range of a dozen supercomputers processing in parallel. In a case like AlTiC mentioned earlier, calculations could take days or even weeks, depending on the number of molecules under consideration in that simulation.

Figure 4 represents an example in which a diamond tip makes an indentation on a silicon carbide (SiC) crystal. The idea is to be able to detect the brittle/ductile transition point in a cutting process of brittle materials such as SiC, silicon, crystallised glass, sapphire, and so on. Existing research in this area at the Precision Micro-Machining Center's Nano-Machining Laboratory, University of Toledo, US, has been successful in detecting the elasto-plastic transition point in the case of indentation of SiC with diamond.

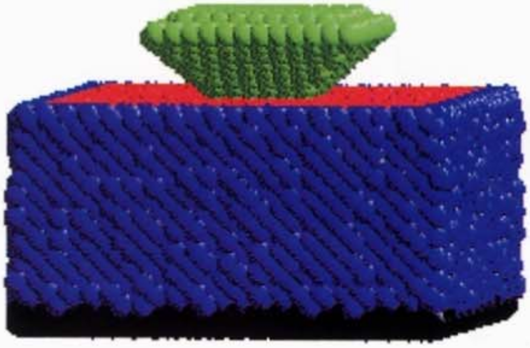


Figure 4: Simulation cell for SiC indentation with diamond.

Nanomachining serves as the bridge between precision engineering and nanotechnology. It may probably not be too much to say that in fact nanotechnology is part of precision engineering or the other way around, except that precision engineering is still under redefinition every day. What is clear is the fact that this "new" field requires interdisciplinary teams to provide the bridge.

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