Manufacturing with Nanoparticle Sprays and Beams

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Technologies that integrate the synthesis of nanoparticles and their controlled deposition onto surfaces will likely play an important role in the development of nanoparticle-based manufacturing. This NIRT project involves an integrated program of research and education that will lead to a fundamental toolkit for manufacturing with nanoparticle sprays and focused beams, illustrated in Figure 1. Nanoparticle sprays, in tandem with a high-rate nanoparticle synthesis process, can be used to coat relatively large areas with nanoparticles. Focused nanoparticle beams, in concert with standard microfabrication techniques, can be used to deposit lines or patterns, or to build three-dimensional objects, made out of nanoparticles.

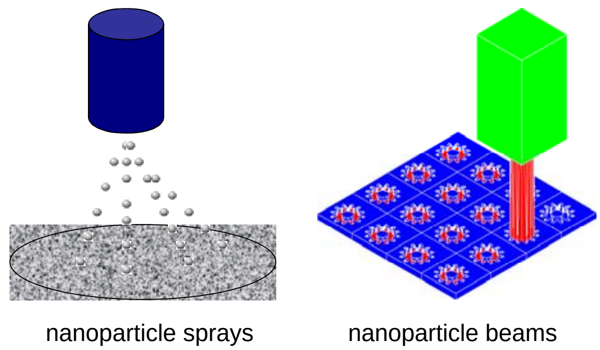

Figure 1. Nanoparticle sprays deposit nanoparticles over wide area by hypersonic impaction. Aerodynamic lenses focus nanoparticles to narrow beams for use in microfabrication.

Processes are being developed in which materials and devices with different nanoparticle-based functionalities are manufactured using nanoparticle sprays and/or beams. To demonstrate this, two different properties of nanoparticle-based systems are being studied: superhardness and photoluminescence. The long-term objective is to develop enabling technologies in which multiple nanoparticle-based functionalities can be integrated on a common platform.

Nanoparticles are synthesized in a high-rate plasma process, in which particles of desired chemi-

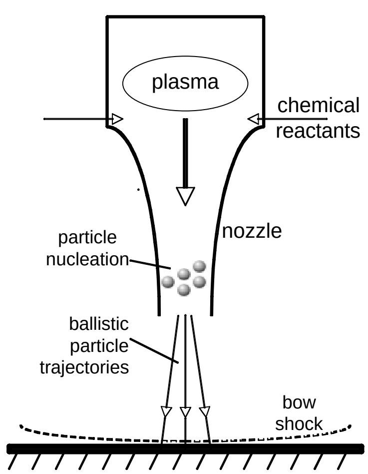

Figure 2. Hypersonic plasma particle deposition.

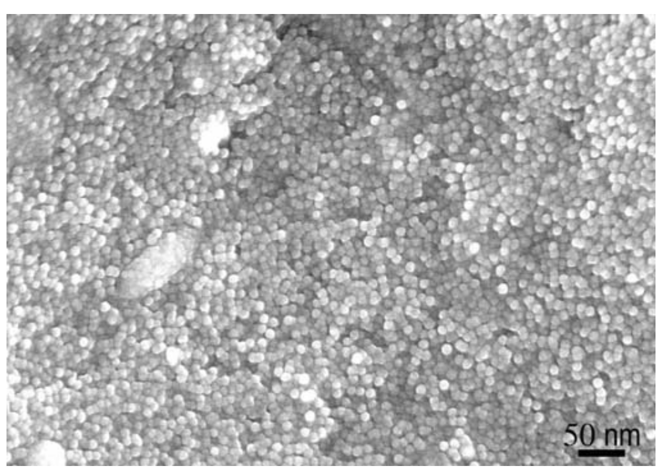

Figure 3. Silicon-titanium nanoparticle film deposited by HPPD.

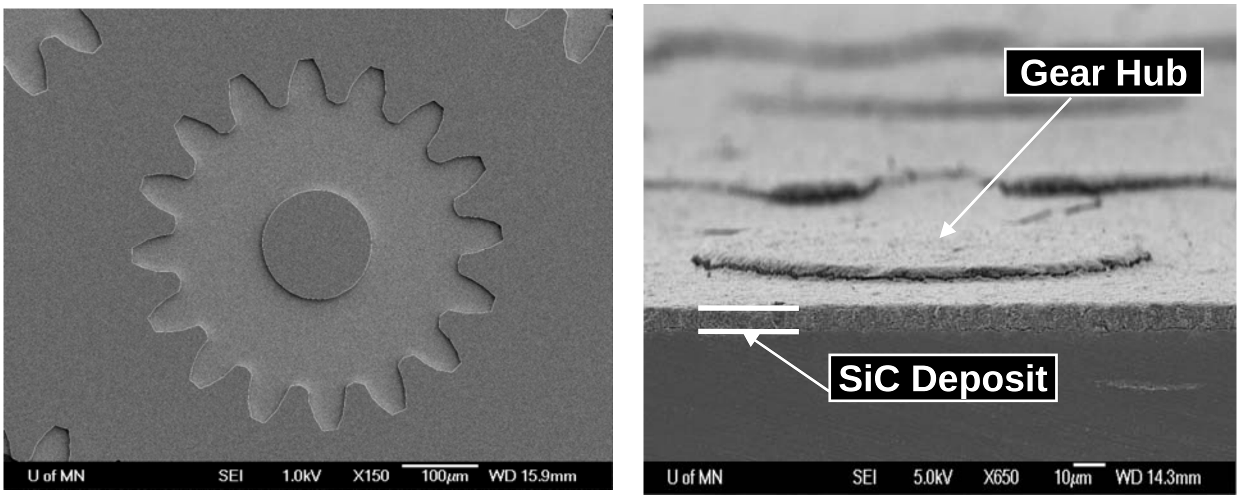

Figure 4. A micromachined silicon gear mold (left) is filled with SiC nanoparticles, shown in cross-section in the SEM image on the right.

cal composition are generated by injecting reactants into a thermal plasma generated by a direct-current arc. The plasma is then expanded through a supersonic nozzle, which drops the temperature and drives particle nucleation. Nanoparticles are sprayed from the nozzle and are accelerated in the hypersonic flow, causing them to impact a substrate at high velocity, creating an adherent nanoparticle film. This process, illustrated in Figure 2, is known as hypersonic plasma particle deposition (HPPD) [2,3]. Figure 3 shows an example of a nanoparticle film deposited by HPPD, in this case a silicon-titanium film.

Alternatively, particles issuing from the nozzle are focused to narrow beams by means of aerodynamic lenses [4]. The focused nanoparticle beams, with a width of a few tens of microns, are used in concert with standard microfabrication techniques to accomplish rapid prototyping using nanoparticles as the building blocks. Figure 4 shows an example of this, in which a miniature

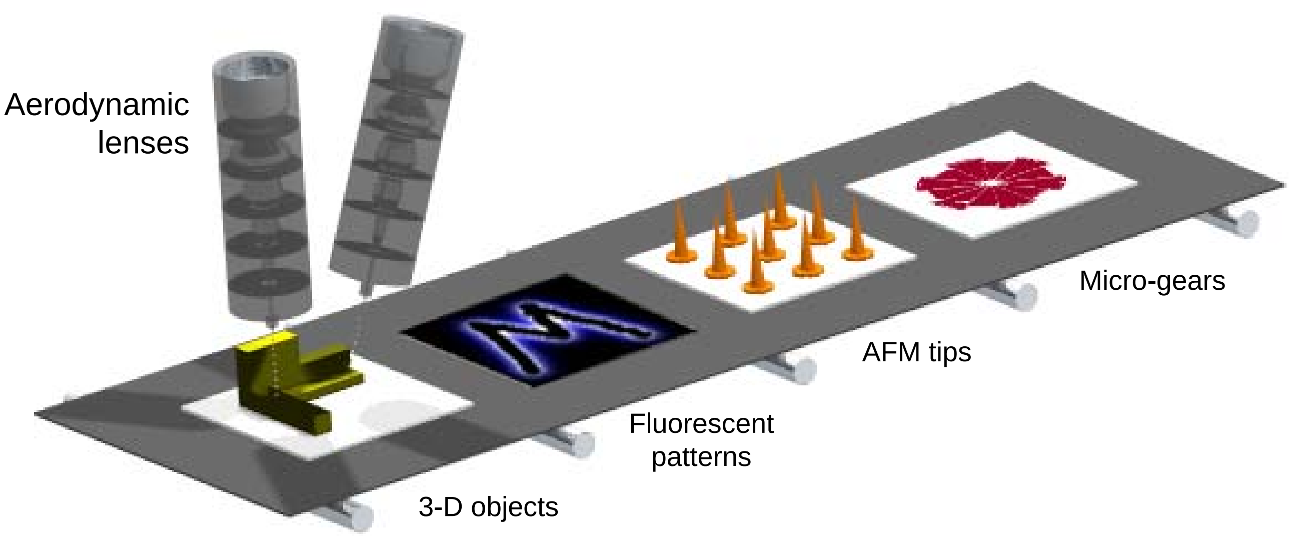

Figure 5. Nanoparticle-based manufacturing assembly line.

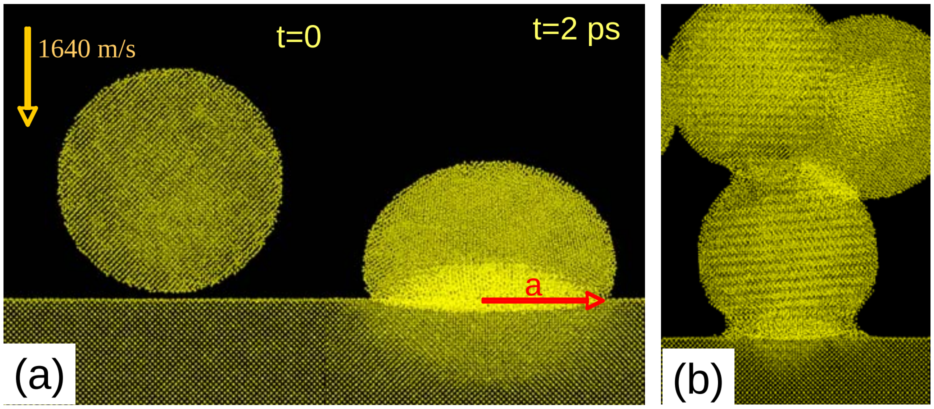

Figure 6. (a) Snapshots from the atomistic simulations for the impact of a single 10-nm-diameter silicon particle at an initial temperature of 1000 K with a silicon substrate at 800 K. (b) Early stages of nanoparticle film formation.

silicon gear mold has been filled with SiC nanoparticles deposited by focused particle beam. Recently we have shown that particles as small as 3 nm in diameter can be effectively focused by aerodynamic lenses [5]. One can imagine arrays of lenses being used to deposit nanoparticles with various compositions and functionalities, so as to accomplish the "nanoparticle-based manufacturing assembly line" illustrated in Figure 5.

Nanoparticles that have been synthesized in work to date include various combinations of the group of elements (Si, Ti, C, N). Size distributions of nanoparticles are measured on-line using an in situ sampling probe interfaced to a scanning mobility particle sizer. Deposits are characterized off-line using an array of diagnostics, including scanning and transmission electron microscopy (SEM, TEM), X-ray diffraction (XRD), energy dispersive X-ray (EDX) analysis, X-ray photoelectron spectroscopy (XPS), Rutherford backscattering spectrometry (RBS) and Auger electron spectroscopy. Mechanical properties of the films are characterized both by nanoindentation and by a pin-on-disk tribometer. Optical properties are examined by means of absorption, photoluminescence, and photoluminescence excitation measurements.

Computational studies using molecular dynamics and related atomistic simulation tools enable us to study fundamental aspects of how a film grows by nanoparticle impact, and of the response of nanoparticles to large compressions. Figure 6 shows an example of such a simulation, in which "snapshots" of the early stages for film formation are shown for 10-nm-diameter silicon particles at 1000 K impact a silicon substrate at 800 K.

References

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