Molecular-Level Self-Assembly Manufacturing

Nanoscale Manufacturing Enables New Material Properties for Military Innovations

NanoSonic, Inc.

Technology and Innovation

Imagine a material that would let the U.S. military have planes that could change the shape of their wings and other body parts during flight, just as birds do, to improve flying under a variety of conditions. This same material would enable sensors to be embedded in the skin of underwater, land, air, and space vehicles, allowing them to monitor conditions in all directions outside the craft, and would allow self-regulating heating and cooling systems to be built into clothing to keep warfighters and others comfortable in harsh environments.

Under this DARPA SBIR, NanoSonic, Inc. (NanoSonic) has developed such a material, aptly called Metal Rubber™. Metal Rubber™ is a lightweight, mechanically flexible material that can be manufactured in sheet and fabric form, and has electrical conductivities approaching those of bulk metals and metal alloys. This unique self-assembled nanocomposite material flexes and stretches like rubber, yet conducts electricity like a solid metal. The material looks like brown plastic wrap but can stretch up to 1,000 percent of its size, immediately recovering its original size, shape, and conductivity when relaxed. It does not degrade when exposed to corrosive or solvent substances such as jet fuel or acetone. During production, NanoSonic is able to vary Metal Rubber's™ characteristics to meet specific engineering requirements, and thus offer a range of possible applications including:

- Flexible electrical circuits, interconnections, and sensors
- Electromagnetic shielding
- Measuring devices to detect large or small mechanical deformations
- Replacement for heavy and/or bulky metal components in wires, motors, and electromagnets
- Artificial muscles in robots and prosthetic muscles in humans
- Stents (tubes inserted into arteries or other body conduits to keep them open)

A segment of a manufactured Metal Rubber™ sheet.

• Electricity-conducting fabrics that conform to any shape

Metal Rubber™ owes its existence to NanoSonic's innovative molecular-level self-assembly manufacturing processes (processes that do not require guidance or management from an outside source), which can be used to fabricate materials having properties not previously obtainable using other production methods.

Electrostatic self assembly (ESA) is a conventional self-assembly method that is used—with modification by NanoSonic—to produce Metal Rubber™. ESA involves treating a base material (such as glass), called a substrate, so that it holds an electrical (positive or negative) charge. The substrate is then dipped into or sprayed by a liquid bath containing ions of opposite charge, so the charged nanoparticles (for example, complexes of polymers, metal or oxide nanoclusters, proteins or other biomolecules) from the bath are attracted to—and bond to—the substrate in a homogeneous thin film arrangement.

The layer is then rinsed in purified water to remove loosely bonded particles, and the process is repeated multiple times, always using a bath containing ions whose charge is opposite those of the previous layer of material. Each bath adds another layer, one molecule deep, to the material. In essence, the material builds itself by the attraction of new molecules to the previous layer. The properties of the resulting material depend on the design of the molecules in each bath and the order of the baths, which controls the order of the multiple molecular layers through the thickness of the material. The process allows control over macroscopic (visible to the human eye) electrical, optical, magnetic, thermal, mechanical, and other properties that are important to various engineering devices and applications.

Conventional self-assembly processing has been limited in both the thickness (typically less than one micron) and the two-dimensional size (typically tens of millimeters square) of materials that may be formed. NanoSonic's innovative variations on conventional processing methods allow thick (millimeters rather than microns) and physically large (sheets up to 4' x 8' so far) free-standing materials to be formed. This is a major advance for military and civilian engineering, which opens up many opportunities to improve existing products and generate new ones.

NanoSonic has created a "library" of self-assembled materials, many of them based on ESA processing, and has demonstrated the synthesis of more than 2000 individual material layers. The company has also developed measurement capabilities to rapidly evaluate materials and new modifications to the self-assembly processes.

Joint Collaborations

NanoSonic has developed collaborative relationships with many defense contractors, government laboratories, and research universities. Such collaborations have led to direct funding, the purchase of prototype materials, free materials analysis, and suggestions for applications outside of those the company originally thought possible. NanoSonic has also received recognition and support from government research laboratories through journal and conference publications, presentations at technical meetings, briefings at specific defense installations, and cooperation with larger defense companies that have direct relationships with end users.

NanoSonic has exclusively licensed nine ESA processing and use patents from Virginia Tech. This DARPA SBIR has enabled NanoSonic to expand its existing network of contacts in the area of flexible electronic materials and devices, an area in which the company had little previous exposure or experience. The DARPA program has also helped to identify potential research, development, and manufacturing partners through technical interchange meetings.

NanoSonic produces large area Metal Rubber™ textiles with high electrical conductivity

NanoSonic has begun discussions with some of these organizations, which may lead to cooperative development agreements.

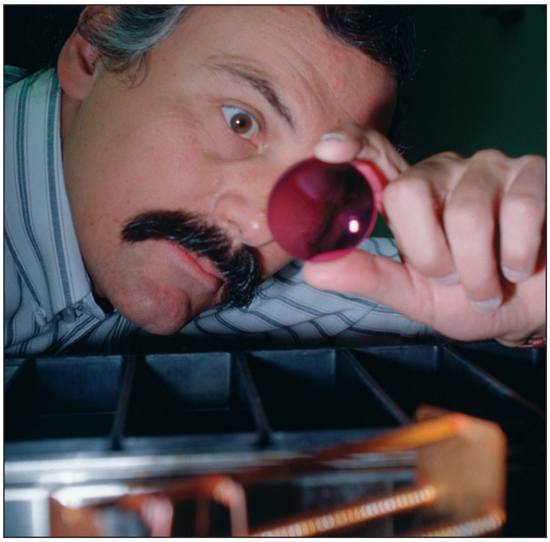
Lessons Learned

- Understand the requirements of the end user and the implications of the technology to be developed. The end-user requirements are key to guiding development and providing a framework for the transition to military and private sector applications and products.
- To achieve desired collaborations, establish many contacts in military organizations and private sector companies, invest the time to maintain those contacts, and bring them a useful technology.
- Commit early to transitioning into specific military and commercial applications. Transitioning is challenging because it requires allocating resources away from research, hiring new people with broader manufacturing experience versus research, and convincing sponsors that your technology merits other applications.
- Participate in technical interchange meetings as much as possible. These exchanges often result in new and novel insights and ideas.

Economic Impact

This DARPA SBIR has had a significant impact on company growth. Since its founding in 1998, NanoSonic has grown from three employees to 62, and annual revenues have grown to $6.5 million. Besides the direct impact of SBIR contract proceeds, funding received under the DARPA SBIR program helped NanoSonic obtain funds from other government organizations and industry partners.

For specific variations of NanoSonic's technology, 100 percent of the funds came from the DARPA SBIR program and, since its founding, approximately 90 percent of the company's technology has had its beginnings in SBIR programs. The company expects about 50 percent of its gross income in the current fiscal year to derive from non-SBIR sources. As a result of the DARPA SBIR program, NanoSonic has an extensive portfolio of issued patents and in-process patent applications related to self-assembly, modifications to self-assembly, methods to form free-standing sheets of multifunctional material via self-assembly, several versions of fabric-type materials formed using self-assembly, and some sensor, actuator and interconnect devices based on those materials.



NanoSonic's modified electro static self assembly process

About the Company

NanoSonic, Inc. is headquartered in Blacksburg, Virginia, approximately two miles from the center of Virginia Tech's Blacksburg campus.

The company maintains 12,000 square feet of newly renovated laboratory and office space. Facilities include equipment for the design, synthesis, and analysis of material precursors (used in ESA baths), the formation of synthesized precursors into thin and thick film materials, the engineering of materials into devices, and the manufacturing of multiple elements using a robotic controlled fabrication line. ■

Company Information

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Dr. Richard O. Claus, President
Founded: 1998
Annual revenue: $6.5 million (2005)
Revenue growth: 20% (2005–2006)
Number of employees: 62