
# ENORMOUS OPPORTUNITIES

## The influence of the MED on micro- and nanomanufacturing.

**BY JIAN CAO, FORMER MANUFACTURING ENGINEERING DIVISION CHAIR (2008–2009)**

Richard Feynman's famous 1959 lecture, "There's Plenty of Room at the Bottom," sketched out a proposal for opportunities at the smallest conceivable scale. That vision has been reaffirmed in recent decades through inventions as varied as active noise-canceling in-ear headphones and anti-bacterial sharkskin surfaces.

The members of the ASME Manufacturing Engineering Division have played a pivotal role in enriching micromanufacturing, based on MED's strength and solid foundation in traditional manufacturing processes. The term micromanufacturing refers to the creation of high-precision products of more than two-and-a-half dimensions (2½D), using a variety of materials and possessing features with sizes ranging from sub-micrometers to a few millimeters. Products with micro- to mesoscale features in such consumer markets as healthcare, communications, electronics, and arts have significantly enhanced the quality of our lives.

Take catheters, a key medical technology that are truly microscale devices, as an example. One catheter with a 2-mm outer diameter can have six internal chambers, or lumens, that are used for a guide wire, light pipe, injection, aspiration, occlusion balloons, and a casting balloon. The miniaturization and the enhanced controllability of catheters has advanced minimally invasive surgeries. Enabling manufacturing technologies for producing catheters include microcutting, microassembly, and microextrusion, which requires a good understanding of temperature-dependent and rate-dependent material properties, interfacial behavior between tooling and material, and metrology and process control.

Another product dependent on micromanufacturing is the printed circuit board (PCB) used in the computer, communications, consumer electronics, industrial, automotive, and aerospace industries. The miniaturization of PCBs has been supported by the microdrilling of vias, which are the holes used for interconnections or for soldering the lead of a component. In an effort to miniaturize, mechanical drilling has been replaced with laser drilling with sizes smaller than 152.4 μm, particularly when dealing with vias that are as small as 25.4 μm.

Anyone who has tried to repair a broken iPhone screen will appreciate how small—down to 0.6 mm outer diameter of the head with a Y shape in the middle—and how various the screws are. Even more challenging miniaturized steel parts are the micro-gears found in the micromotors used for precision motion control. These are critical components in medical devices, such as ventilation equipment, surgical hand tools, respiratory devices, biopsy systems, and medical pumps, as well as in robots, automation, and the automotive industry. These tiny components, with the outer diameter of a 13-tooth gear being only 1/6 of a coffee bean, are an essential part of a micromotor market. Key manufacturing processes for these parts are in the category of microforming—and the requirement of strength and wear behavior of tooling brings challenges to other micromanufacturing processes.

Those three examples are only the tip of the iceberg for the vast applications of non-silicon 2½D products, which span over medical implants, portable electronic devices, cameras, wireless devices, microscale fuel cells, micro-reactors, microfluidic systems, micro-nozzles, optical lenses, and much more.

In 2004, with the encouragement of the former MED Chair (1985-1986) Warren DeVries and Delcie Durham, I initiated the World Technology Evaluation Study on Micromanufacturing with the support of more than 10 programs at the National Science Foundation, the Office of Naval Research, the Department of Energy, and the National Institute of Standards and Technology. The study aimed to identify scientific challenges, technological gaps, and commercialization trends by benchmarking efforts in the U.S., Europe, and Asia. The study was co-led by the former MED Chair (1994-1995), Kornel Ehmann of Northwestern, and the late Richard E. DeVor of the University of Illinois at Urbana-Champaign. It was joined by academic leaders in their respective fields, such as Beth Allen of the University of Minnesota, David Bourell of the University of Texas at Austin, Martin Culpepper of the Massachusetts Institute of Technology, Thom J. Hodgson of North Carolina State University, Thomas R. Kurfess of the Georgia Institute of Technology, Marc Madou of the University of California at Irvine, and Kamlakar Rajurkar of the University of Nebraska at Lincoln.

The report, published in 2005, stimulated many R&D investments, as well as notable activities in the MED's Manufacturing Science and Engineering Conference (MSEC). For example, at MSEC 2006, Burak Ozdoganlar of Carnegie Mellon University and Donald Risko of Ex-One organized the symposium "Micro-manufacturing Processes and Equipment," and Martin Culpepper of MIT, Curtis Taylor of Virginia Commonwealth University (now at the University of Florida), and Ajay Malshe of the University of Arkansas (now at Purdue University) organized "Nano and Micro Mechanical and Related Hybrid Tools for Nanomanufacturing."

Just two years later by MSEC 2008, there were nine symposia related to micro- and nanomanufacturing.

Nanomanufacturing is about the manipulation of matter at scales between 1 and 100 nanometers. Given the vast federal investment of R&D in Nanotechnology, about $27 billion since the inception of the National Nanotechnology Initiative in 2001 as reported by the Office of Science and Technology Policy, and given the typical 10- to 20-year timeframe from discovery to commercialization, the impact of nanomanufacturing has started to rise rapidly and is expected to bring about $100 billion in annual growth in U.S. commercial revenue for every $1 billion in investment, as stated in the 2016 National Academies of Sciences, Engineering, and Medicine report. The ability to synthesize materials at the nanoscale has undoubtedly created unprecedented opportunities for applications in drinking water, clean energy, regenerative medicine, and other important areas.

> **"Opportunities for manufacturing engineers have never been so bright."**

Given the global importance of micro- and nanomanufacturing, in 2011, with the encouragement of the former MED Chair (1991-1992) Shiv G. Kapoor of the University of Illinois at Urbana-Champaign, I proposed to establish a new ASME *Journal on Micro- and Nano-Manufacturing* (*JMNM*) with an inaugural issue in March 2013. I humbly served as the Founding Technical Editor for the *JMNM*, until the editorship transitioned in 2018 to Nicholas Fang of MIT. Most recently, ASME established the Kornel F. Ehmann Manufacturing Medal awarded annually to the best paper published in the *JMNM*.

The future of micro- and nanomanufacturing—and perhaps molecular manufacturing—will require mechanical engineers to work closely with all other disciplines to solve system-level grand challenges in sustainability, health, security, and the joy of living as identified in the National Academy of Engineering's *14 Grand Challenges for Engineering in the 21st Century*. To strive for excellence and to prepare our workforce for those grand challenges, we need to understand the fundamentals at various scales. Moreover, boundaries between those length scales have become interwoven. For example, in additive manufacturing, adding nanoparticles to strengthen material's mechanical behaviors while controlling the melt-pool behavior at the microscale to mesoscale, can yield lightweight and high-performance parts at the macroscale.

As we venture to become a multiplanetary species that betters ourselves and our surrounding environment, opportunities for manufacturing engineers, to lead and to collaborate with other disciplines, have never been so bright, as the MED steps into its second 100 years. **ME**

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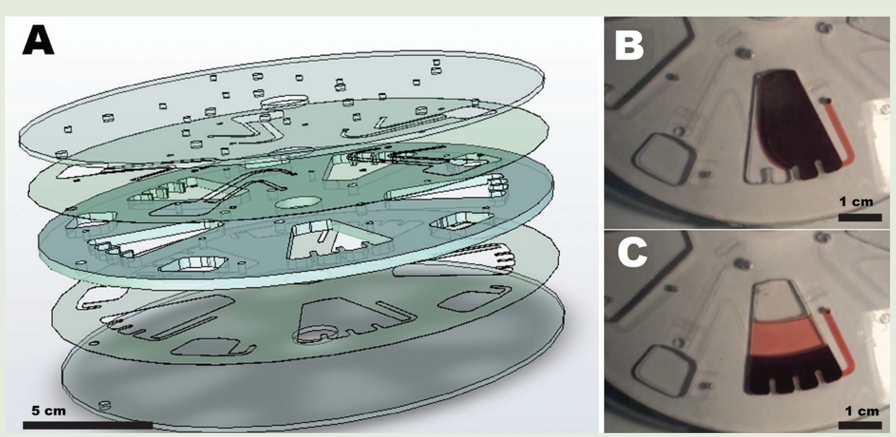
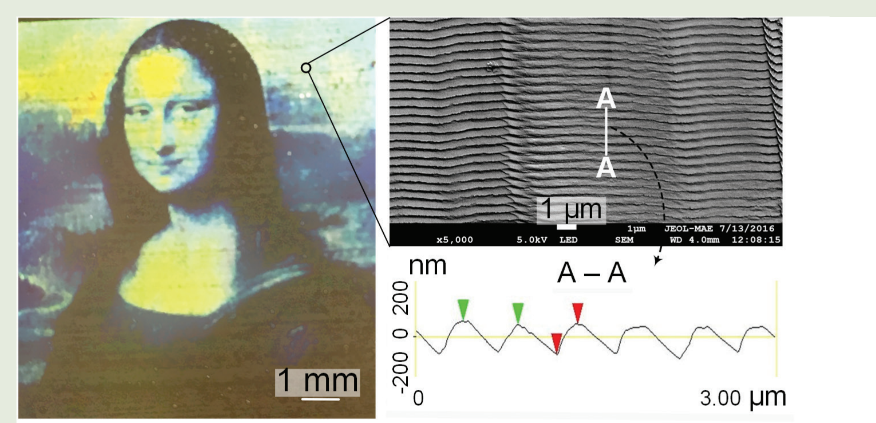
*High-throughput microfluidic device for blood plasma separation.* Images: M. Madou, UC Irvine




*Color generated by micro-machining, without chemicals.* Images: P. Guo, Northwestern Univ.

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