

# **30 Years of Nanoimprint: A Transformative Technology Revolutionizing Research, Nanomanufacturing, and Industry**

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Nanostructures offer a unique pathway to discoveries, innovations, and breakthroughs across a wide range of disciplines and industries. As the feature size of these structures shrinks below fundamental length scales, conventional theories may no longer apply, leading to new unique properties and enabling the creation of superior products once thought unattainable. Yet, the promise of nanostructures cannot be fully realized or commercialized unless we have a nanomanufacturing technology capable of producing them with high throughput, low cost, and often over large areas.

Among all existing technologies for manufacturing nanostructures, nanoimprint is clearly one of the most promising and impactful. This is because nanoimprint offers an unmatched combination of the smallest feature size ( $<0.5$  nm), the largest area (e.g., wallpaper-sized), the broadest flexibility, and the lowest cost, along with curved or soft surface patterning, zero scattering, 3D capabilities, and high throughput.

Over the past three decades, nanoimprint has evolved from being initially met with fierce skepticism—once considered nearly impossible for nanoscale lithography and patterning—to becoming a paradigm-shifting technology that has transformed both academia and industry. Today nanoimprint is widely used in research and industrial manufacturing across well over 10 distinct fields. Nanoimprint-enabled products collectively generate over \$10 billion in annual revenue. These products span a broad range of industries, including optics and photonics (e.g., virtual reality (VR), augmented reality (AR), meta-optics, smartphones, displays, LEDs, solar cells, optical sensors, and communications), biotechnology (e.g., gene sequencing and biosensing), metamaterials, microfluidics, semiconductor ICs, energy storage (e.g. batteries), pharmaceuticals, medicine, security features (e.g., banknotes and identifications), data storage, and more.

This year marks a historic milestone—30 years of nanoimprint [1, 2]. As the creator of the field of nanoimprint and its applications, the leading advocate who defended it against overwhelming skepticism during its infancy, and a primary driving force behind its advancement, the author will highlight the past, present, and future of nanoimprint.

[1] S. Y. Chou, P. R. Krauss, and P. J. Renstrom, "Imprint of Sub-25 nm Vias and Trenches in Polymers," *Appl. Phys. Lett.*, 67 (21), 3114 (1995).

[2] S. Y. Chou, P. R. Krauss, and P. J. Renstrom, "Imprint Lithography with 25-Nanometer Resolution," *Science*, 272, 85 (1996).