

News & Views

Open Access

Transforming scattering into a seed of a nanometric blade

Tong Ling^{1,2*}  and Shih-Chi Chen^{3,4*} 

Abstract

Chai et al. converted interferometric scattering from a persistent optical limitation into an effective tomoslicing technique, which delivers an unprecedented 7-nm kerf width and almost lossless wafering. Furthermore, this method is a robust and scalable approach for the low-waste manufacturing of transparent crystals and semiconductor substrates.

Keywords: Interferometric scattering, Optical tomoslicing, Ultrafast laser wafering, Kerf-free manufacturing, Transparent solids

Ultrafast lasers have steadily expanded the scope of optical manufacturing, from photonic structures in crystals to sub-20-nm surface nanowriting and the stealth dicing of hard wafers. In recent years, the lateral resolution of optical manufacturing has improved significantly through near-field, high-numerical aperture (NA) lenses and super-resolution schemes, thereby enabling advanced surface structuring, additive fabrication, and localised subsurface writing^{1–13}, as summarised in Table 1. However, such enhancement cannot directly translate to a small kerf when slicing crystals or transparent solids owing to the limited depth of field of a Gaussian beam. Although utilising Bessel beams may significantly extend the field depth, the resulting kerf widths measure hundreds of nanometres with rough surfaces¹⁴. This is not merely an engineering inconvenience. For high-value transparent materials such as laser crystals and semiconductor substrates, every additional micrometre of kerf translates into wasted

feedstock, thicker polishing allowances, and higher costs. This bottleneck remains a longstanding problem in laser manufacturing.

Instead of pursuing conventional approaches such as optimising NAs or focusing techniques, Chai et al. transformed the physical role of scattering^{4,5,8,9,13}. In most laser-processing scenarios, scattering is a detrimental mechanism, which perturbs focusing, redistributes energy, and degrades precision. Chai et al. inverted this logic. They intentionally created an initial nanopore via femtosecond-laser-induced micro-explosion and then used the nanopore as a seed scatterer. When the incident beam was laterally offset from the seed within a critical distance (approximately 200 nm in fused silica; Fig. 1b–d), the scattered field interfered with the undisturbed portion of the beam, thus yielding a sufficiently strong localised intensity maximum to generate a secondary nanopore. The secondary pore became the next scatterer, and the process was repeated in a controlled cascade. In other words, the structure being written participated in writing the next structure. This interferometric-scattering mechanism achieves energy localisation independent of the original focal ellipsoid. By adjusting the pulse offset, the authors steered the trajectory and orientation of sequential

Correspondence: Tong Ling (tong.ling@ntu.edu.sg) or Shih-Chi Chen (scchen@mae.cuhkedu.hk)

¹School of Chemistry, Chemical Engineering and Biotechnology, Nanyang Technological University, Singapore 639798, Singapore

²School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore

Full list of author information is available at the end of the article.

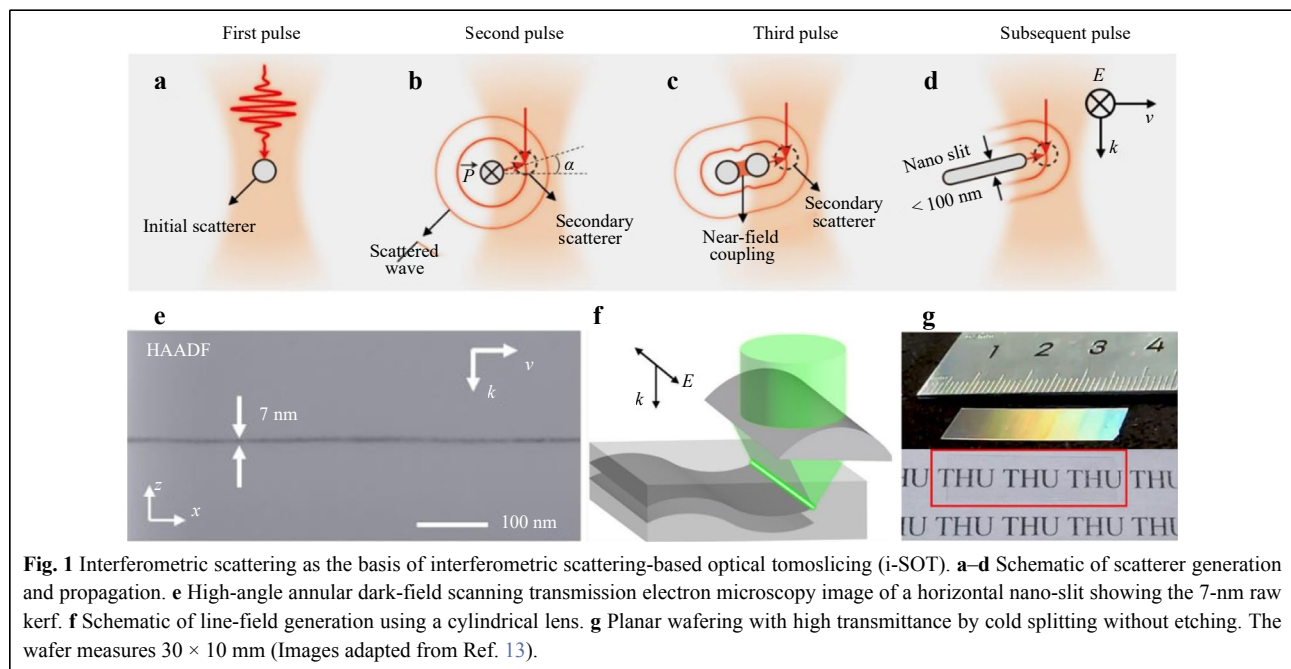
© The Author(s) 2026



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

Table 1 Representative recent advances in optical manufacturing in terms of feature resolution and depth-to-width aspect ratio.

Processing technique	Material	Characteristic advance
Three-dimensional (3D) femtosecond laser writing ¹	Yttrium aluminium garnet (YAG) and sapphire	3D nanostructures with ~100 nm feature sizes
Femtosecond projection two-photon lithography ²	Photoresist	Nanowires with lateral widths of 130–140 nm and axial heights down to 175 nm
Optical far-field-induced near-field breakdown ³	TiO ₂ films	Surface nanowriting with spatial resolution < 20 nm
Picosecond laser-induced micro-explosion ⁴	4H-SiC	Picosecond slicing with cutting width < 2 μ m and 250 μ m thick wafers
Longitudinal laser-field material processing ⁵	Sapphire, Si, and Cu surfaces	10–30-nm features with an aspect ratio > 16 in the far field
Kinetically regulated material assembly ⁶	Metals, two-dimensional (2D) materials, oxides, and diamond	3D nanostructures with 20–200-nm resolution
Photoexcitation-induced chemical bonding ⁷	Semiconductor quantum dots	3D nanoprinting with a minimum lateral linewidth of 81 ± 4 nm
Picosecond laser stealth dicing ⁸	4H-SiC	Stealth dicing with a chipping width < 3 μ m and section roughness < 500 nm
Super-stealth dicing ⁹	Transparent solids including fused silica, LiTaO ₃ , LiNbO ₃ , YAG, Ce:YAG, and β -Ga ₂ O ₃	Nanometric-precision dicing with cutting widths measuring tens of nanometres and aspect ratios of 1,000–10,000
3D nonlinear laser nanolithography ¹⁰	Silicon	Embedded nanostructures with feature sizes down to 100 ± 20 nm deep inside silicon
Laser-induced periodic surface structures ¹¹	2D NbOI ₂	Groove widths down to ~14.5 nm ($\sim \lambda/73$) fabricated in ambient air
Wet chemical etching-assisted aberration-enhanced single-pulsed femtosecond laser-supplemented nanolithography ¹²	Crystals, glasses, and Si-based semiconductors	25-nm features, aspect ratios > $10^4:1$, and 10 mm ² holey nanostructures
Interferometric scattering-based optical tomoslicing ¹³	Fused silica, YAG, and MgAl ₂ O ₄	7-nm kerf, mass loss < 1%, 30×10 mm slicing, and theoretical industrial efficiency up to 400 mm ² /s



nanopores. Moreover, by shifting from a point focus to a line field generated using a cylindrical lens (Fig. 1f), they translated the same principle into interferometric scattering-based optical tomoslicing (i-SOT), which is a

plane-slicing strategy instead of a conventional crack-guided separation process. This strategy offers high throughput (1 m/s) and scalability, and the resulting surface simultaneously offers superior quality ($R_a = 9$ nm)¹³.

The performance metrics explain the importance of this concept. Additionally, the experiments were conducted with a modest NA of 0.6, thus avoiding the requirement for extremely high-NA optics. In fused silica, i-SOT yielded raw kerf widths down to 7 nm (Fig. 1e). Furthermore, the method accommodates geometries rarely attainable via conventional wafering, including multilayer slicing, 45° tilted planes, and wavy cross-sections. In addition to fused silica, Chai et al. applied i-SOT to crystalline yttrium aluminium garnet (YAG) and MgAl_2O_4 , thus yielding ultrathin wafers that were approximately 8.6–9.5- μm thick and demonstrating that the sliced YAG plates retain notable mechanical integrity. i-SOT employs a line field instead of point-by-point raster scanning, thereby offering high throughput and precision. A 30×10 mm transparent slice can be created directly (Fig. 1g), and the authors predict that by adopting industrial-class femtosecond sources, the theoretical slicing efficiency may reach 400 mm^2/s . Most importantly, combining ultrathin wafering with nanometric kerfs reduces mass loss from approximately 30% to below 1%, thus bringing laser wafering close to an almost-ideal, “kerf-free” manufacturing process¹³.

Perhaps the most profound impact of this study is conceptual. Over the past two decades, researchers have progressively leveraged principles from super-resolution optical imaging, nonlinear thresholding, and near-field confinement to enhance fabrication resolution. Chai et al. provided a different perspective: the medium can be actively engineered to serve as an interferometric contributor to the manufacturing process. Once scattering is seeded, directed, and cascaded, this process ceases to exert a parasitic effect and becomes a tool for energy localisation. This reversal is elegant yet practical and represents a family of laser-manufacturing strategies where sub-diffraction precision, high throughput, and low material loss are pursued simultaneously instead of through mutual compromise. For transparent solids, light scattering may have just changed from a nuisance into the blade itself^{3,5,9,13}.

Author details

¹School of Chemistry, Chemical Engineering and Biotechnology, Nanyang Technological University, Singapore 639798, Singapore. ²School

of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore. ³Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong, China. ⁴Centre for Perceptual and Interactive Intelligence, Hong Kong Science Park, Hong Kong, China

Conflict of interest

The authors declare no competing interests.

Received: 24 June 2026 Revised: 15 July 2026 Accepted: 16 July 2026

Published online: 10 October 2026

References

- Ródenas, A. et al. Three-dimensional femtosecond laser nanolithography of crystals. *Nature Photonics* **13**, 105–109 (2019).
- Saha, S. K. et al. Scalable submicrometer additive manufacturing. *Science* **366**, 105–109 (2019).
- Li, Z. Z. et al. O-FIB: far-field-induced near-field breakdown for direct nanowriting in an atmospheric environment. *Light: Science & Applications* **9**, 41 (2020).
- Han, S. F. et al. Laser slicing of 4H-SiC wafers based on picosecond laser-induced micro-explosion via multiphoton processes. *Optics & Laser Technology* **154**, 108323 (2022).
- Li, Z. Q., Allegre, O. & Li, L. Realising high aspect ratio 10 nm feature size in laser materials processing in air at 800 nm wavelength in the far-field by creating a high purity longitudinal light field at focus. *Light: Science & Applications* **11**, 339 (2022).
- Han, F. et al. Three-dimensional nanofabrication via ultrafast laser patterning and kinetically regulated material assembly. *Science* **378**, 1325–1331 (2022).
- Liu, S. F. et al. 3D nanoprinting of semiconductor quantum dots by photoexcitation-induced chemical bonding. *Science* **377**, 1112–1116 (2022).
- Wen, Q. L. et al. Study on picosecond laser stealth dicing of 4H-SiC along $[11\bar{2}0]$ and $[1\bar{1}00]$ crystal orientations on Si-face and C-face. *Optics & Laser Technology* **162**, 109300 (2023).
- Li, Z. Z. et al. Super-stealth dicing of transparent solids with nanometric precision. *Nature Photonics* **18**, 799–808 (2024).
- Asgari Sabet, R. et al. Laser nanofabrication inside silicon with spatial beam modulation and anisotropic seeding. *Nature Communications* **15**, 5786 (2024).
- Guan, Y. C. et al. Far-field femtosecond laser-driven $\lambda/73$ super-resolution fabrication of 2D van der Waals NbO_2 nanostructures in ambient air. *Nature Communications* **16**, 4149 (2025).
- Chen, Z. et al. 25 nm-Feature, 10^4 -aspect-ratio, 10 mm^2 -area single-pulsed laser nanolithography. *Nature Communications* **16**, 7434 (2025).
- Chai, Y. et al. Interferometric scattering for optical tomoslicing of transparent solids. *Light: Science & Applications* **15**, 297 (2026).
- Stoian, R. et al. Ultrafast Bessel beams: advanced tools for laser materials processing. *Advanced Optical Technologies* **7**, 165–174 (2018).