GDR Groupement de recherche
EMILI Étude des milieux ionisés Plasmas froids créés par décharge et laser

LP3

amU Aix Marseille Université

cnrs

Modification de matériaux semi-transparents par lasers à impulsions ultra-brèves

Modification of semi-transparent materials by ultra-short pulse lasers

Pol Sopeña

LP3 - Lasers, Plasmas et Procédés Photoniques (UMR 7341)

pol.sopena-martinez@univ-amu.fr

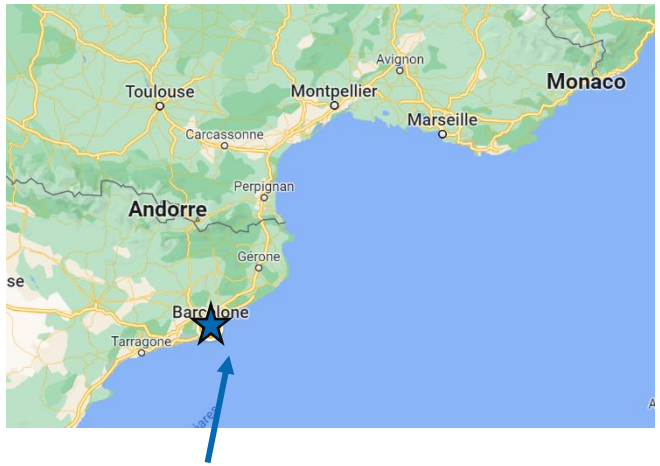
27th-30th October 2025 Laboratoire Hubert Curien Saint Étienne, France

Background

Pre-doc (Universitat de Barcelona)

UNIVERSITAT DE BARCELONA

Dep. Física Aplicada

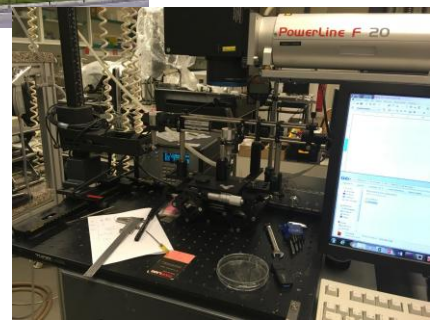


2010-2014

Physics Bachelor

2014-2015

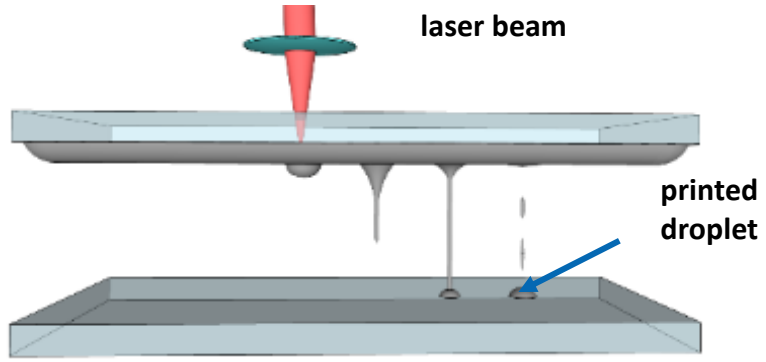
Advanced Physics Master



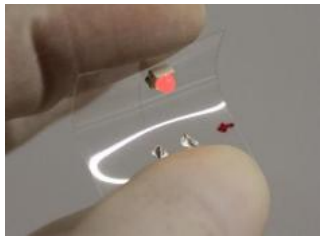
PhD program (Universitat de Barcelona)

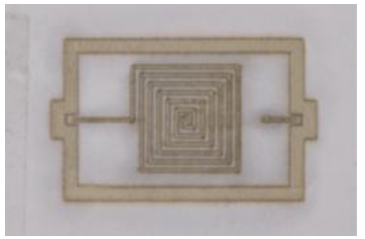
2015-2020

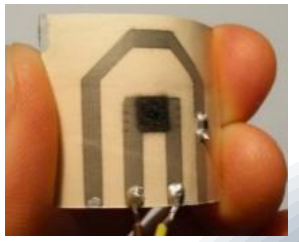
Laser-induced forward transfer



printed electronics components





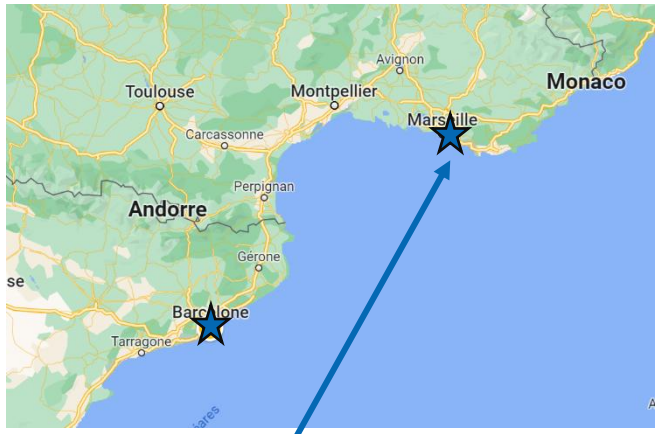


Post-doc → Chargé de Recherche (Aix-Marseille Université - CNRS)

2021-2024

Laboratoire LP3
(Lasers, Plasmas et Procédés Photoniques)

- **ERC Project (2021-2022)**
- **Margarita Salas (2022)**
- **CIVIS3i MSCA (2022-2024)**



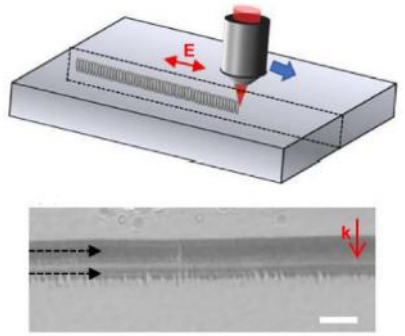
2024-present

Chargé de Recherche CNRS

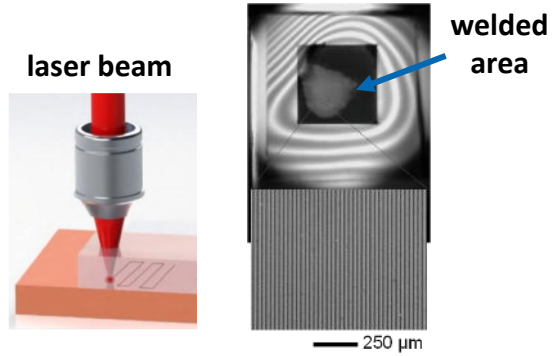
(Permanent research fellow)

Infrared and ultrafast laser processing

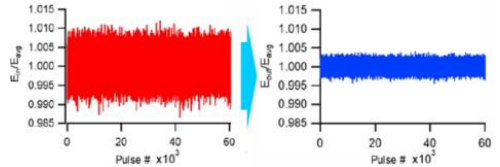
bulk Si and GaAs modification



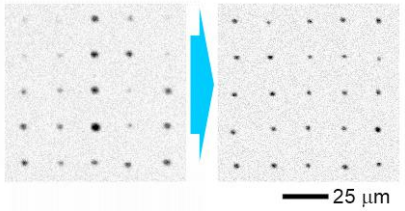
semiconductor laser welding



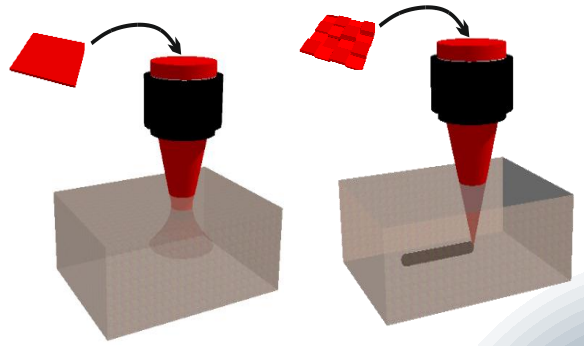
nonlinear precision enhancement



no stabilization — after stabilization



processing of scattering materials



Motivation

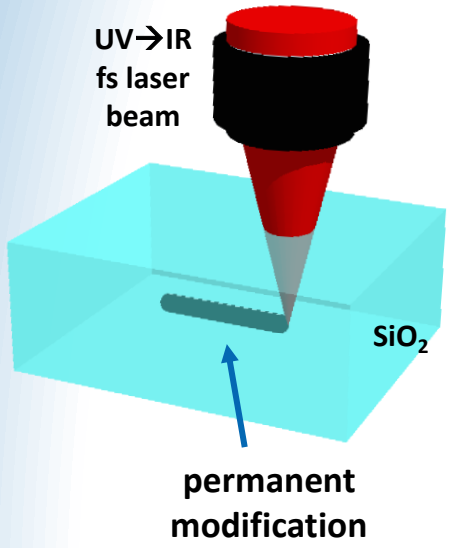
Dielectrics

Silica (SiO_2)

- Bandgap: 9.0 eV
- n: 1.45

Ultrashort pulses in dielectrics

- Femtosecond pulses (~ 10^{-13} s)
- Extreme intensities (~10^{15} W/cm^2)
- Multiphoton absorption



Semiconductors

Silicon (Si)

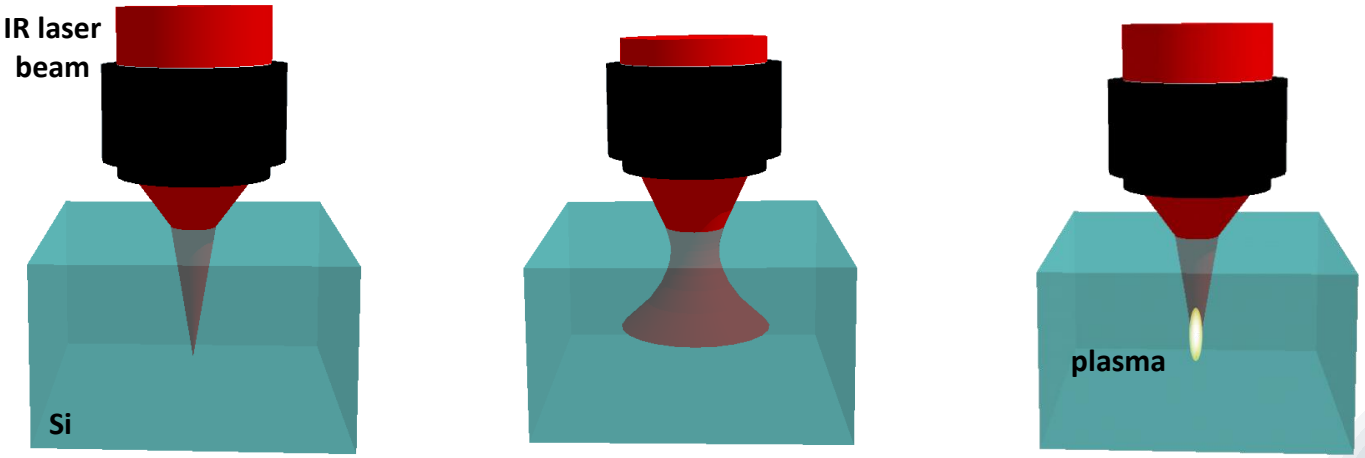
- Bandgap: 1.1 eV
- n: 3.5

Gallium Arsenide (GaAs)

- Bandgap: 1.4 eV
- n: 3.4

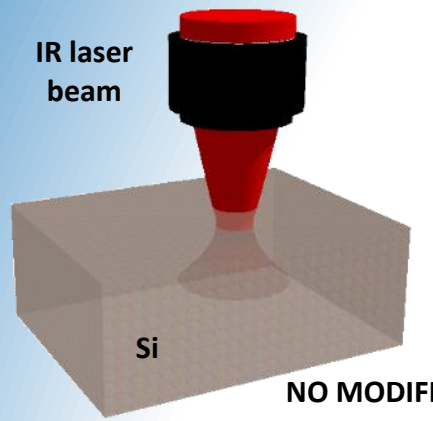
Ultrashort pulses in semiconductors → 2-3 photon absorption (near-IR)

- Reduced numerical aperture (high n)
- Beam defocusing (nonlinear propagation)
- Pre-focal plasma (screening)



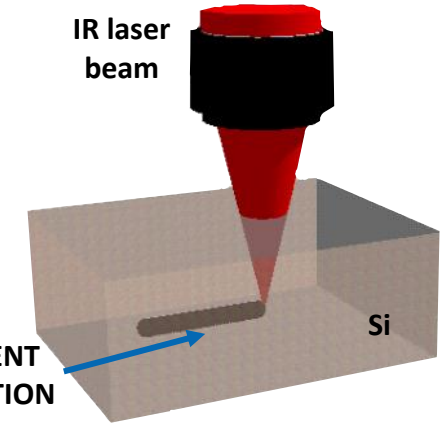
NO MODIFICATION

Semiconductors



NO MODIFICATION

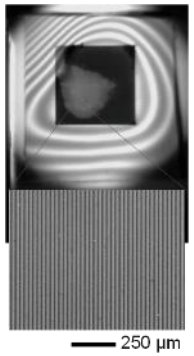
Compensation strategies



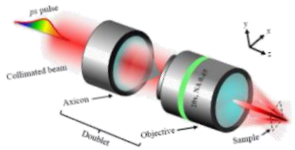
PERMANENT MODIFICATION

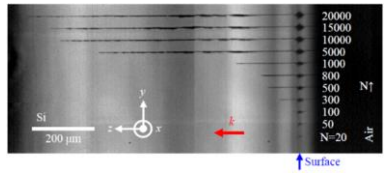
Temporal strategies

nanosecond pulses

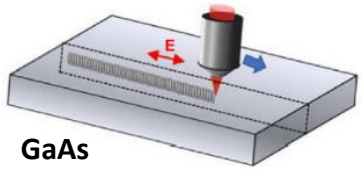


picosecond pulses

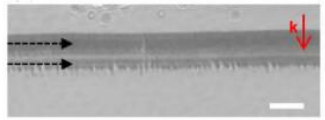




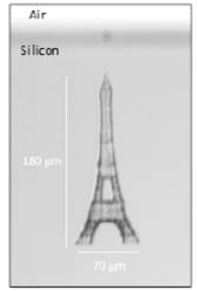
ultrashort bursts

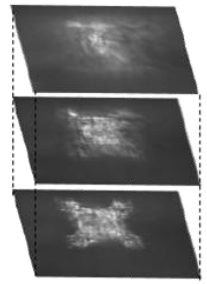


GaAs



plasma optics



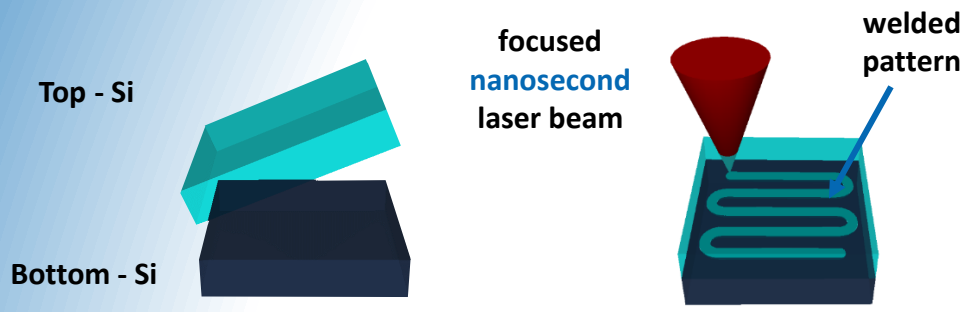


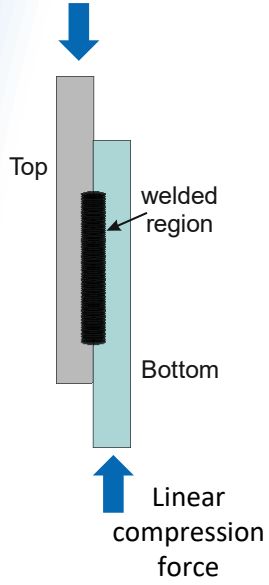
Nanosecond laser welding

P. Sopeña, A. Wang, A. Mouskeftaras, D. Grojo, Transmission Laser Welding of Similar and Dissimilar Semiconductor Materials. Laser Photon. Rev. 16, 2200208 (2022)

Intimate contact

Laser irradiation

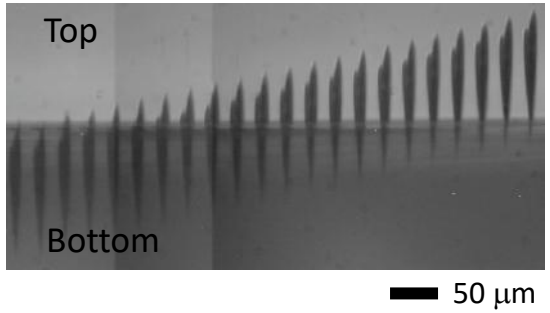




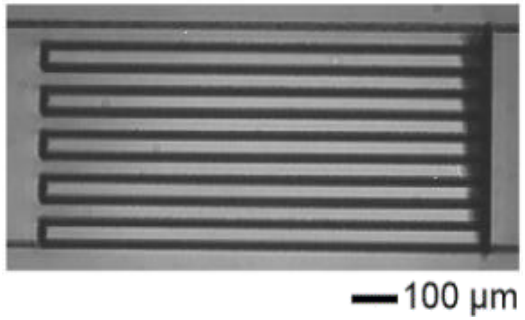
Shear joining strength (Si-Si)

32±10 MPa

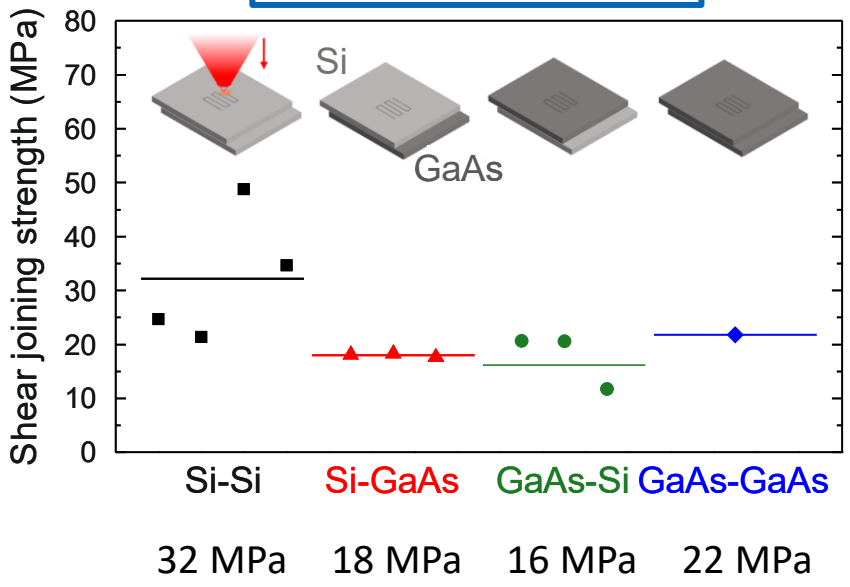
Lateral view



Top view



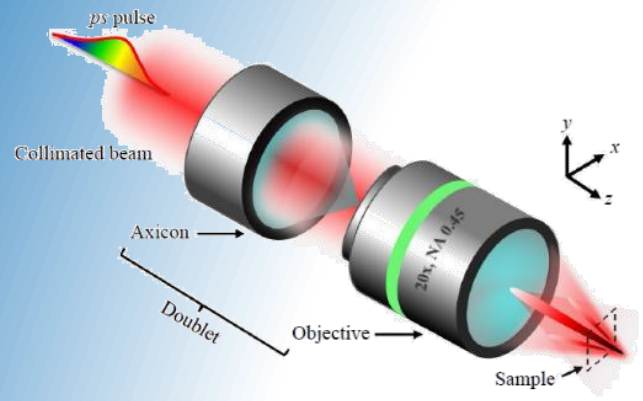
Dissimilar semiconductors



> 10 MPa

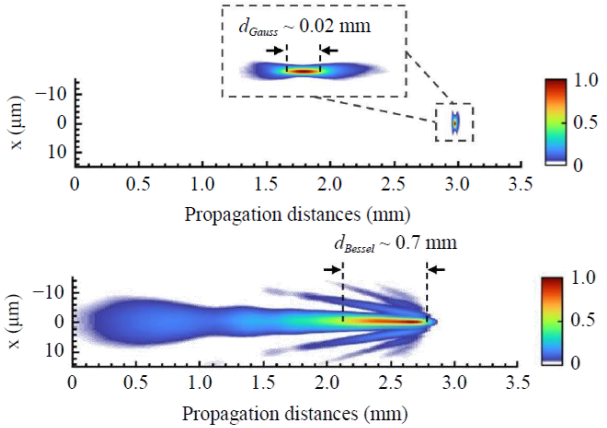
Picosecond pseudo-Bessel beams

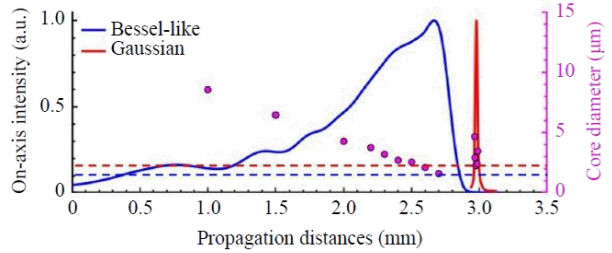
N. Ganguly, P. Sopeña, D. Grojo, Ultra-high-aspect-ratio structures through silicon using infrared laser pulses focused with axicon-lens doublets. Light: Adv. Manuf. 5, 22 (2024)

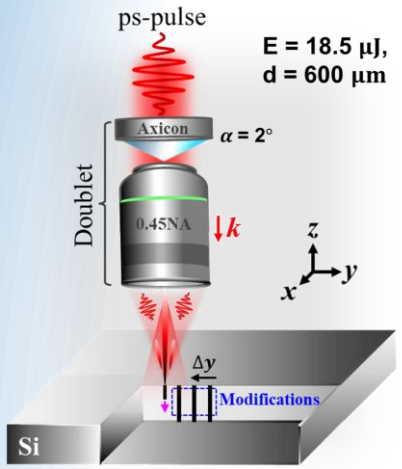


Gaussian beam

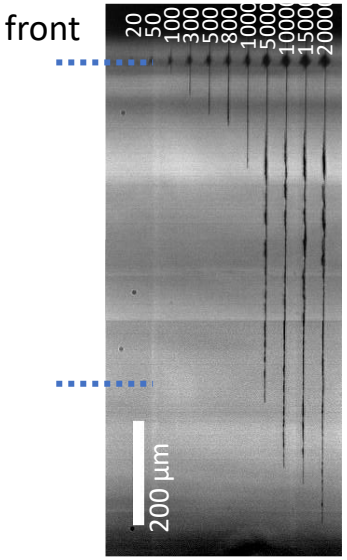
Pseudo-Bessel beam



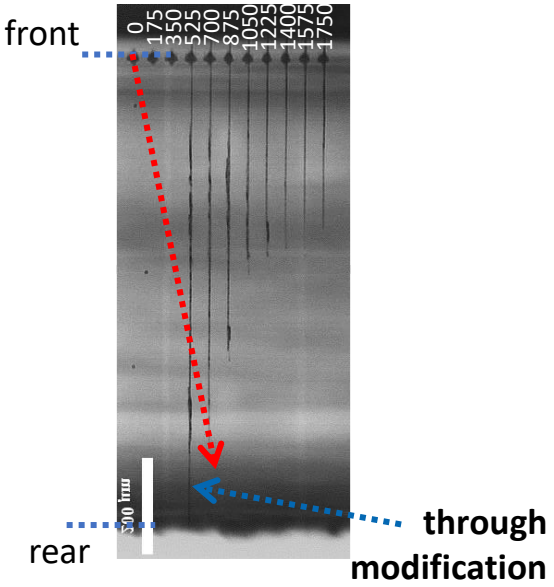




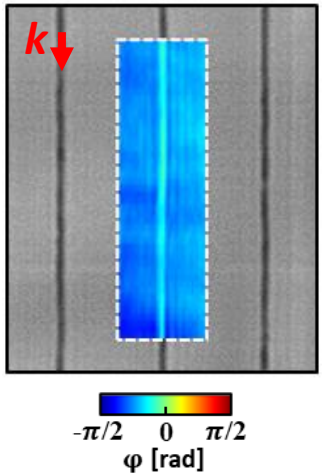
Number of pulses



Hotspot depth (µm)



phase microscopy

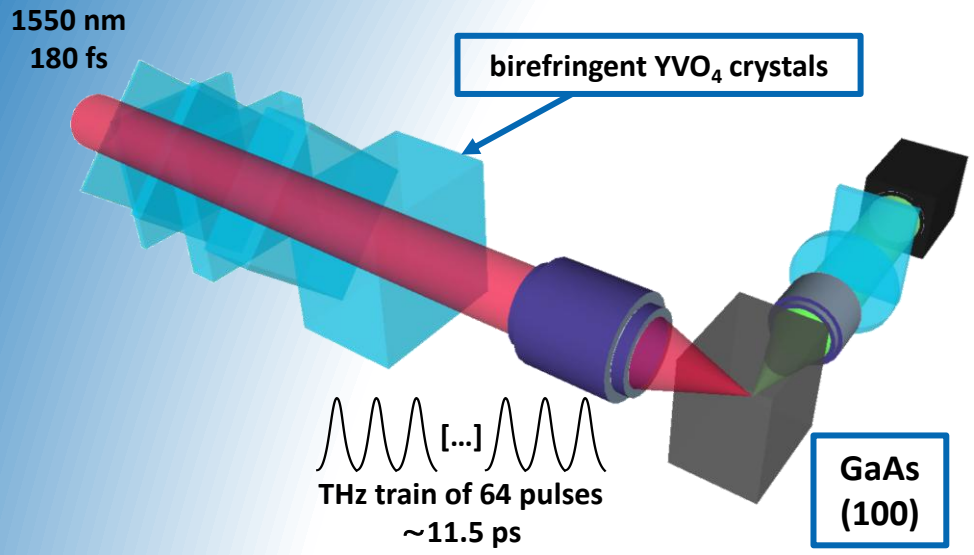


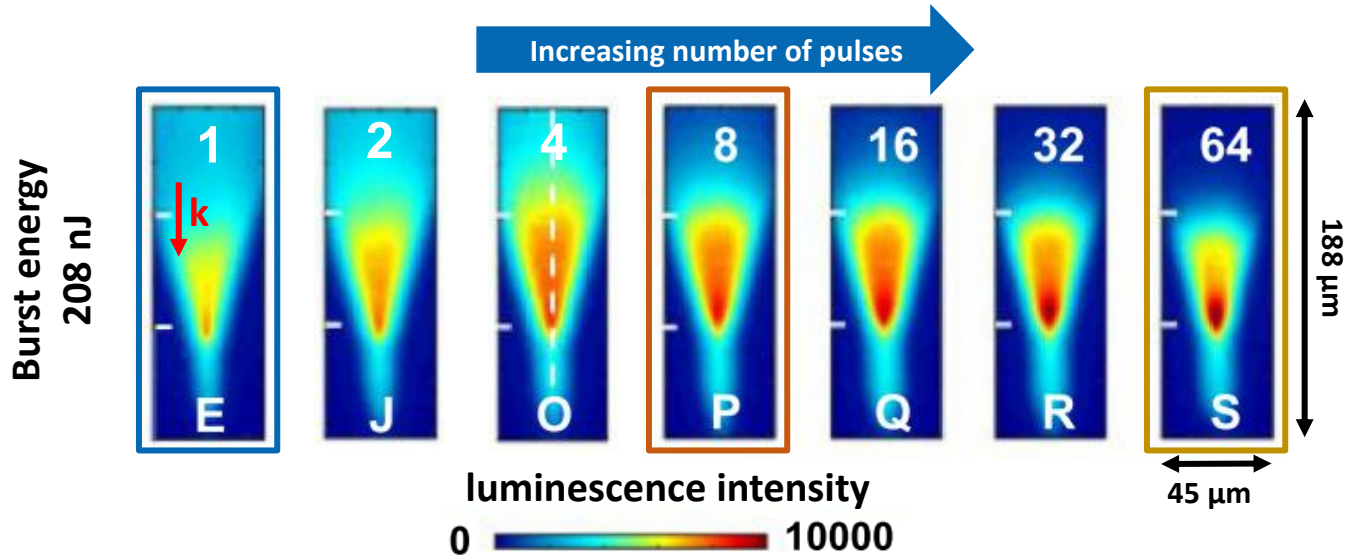
Δn ~ 10^{-2} (1%)
Amorphous structures

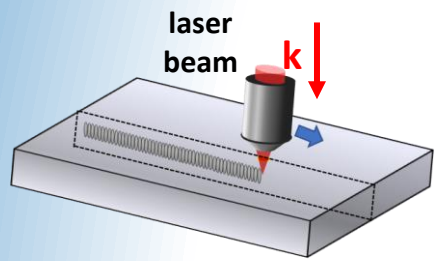
Light guiding

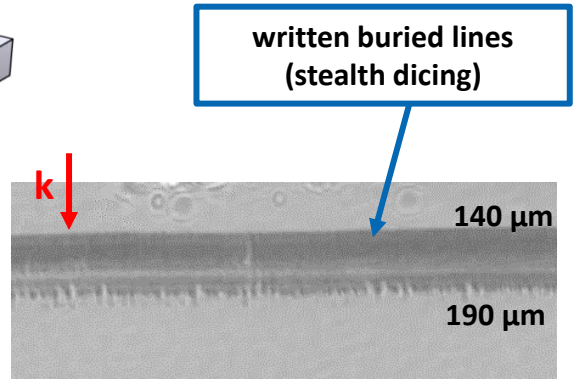
Ultrashort THz repetition rate bursts

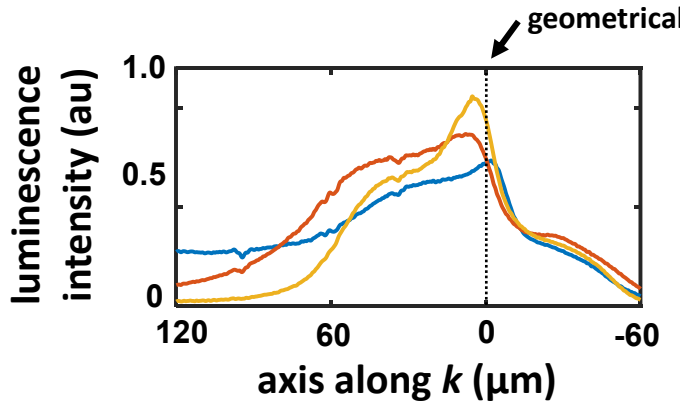
A. Wang, P. Sopeña, D. Grojo, Burst mode enabled ultrafast laser inscription inside gallium arsenide. Int. J. Extrem. Manuf. 4, 045001 (2022)









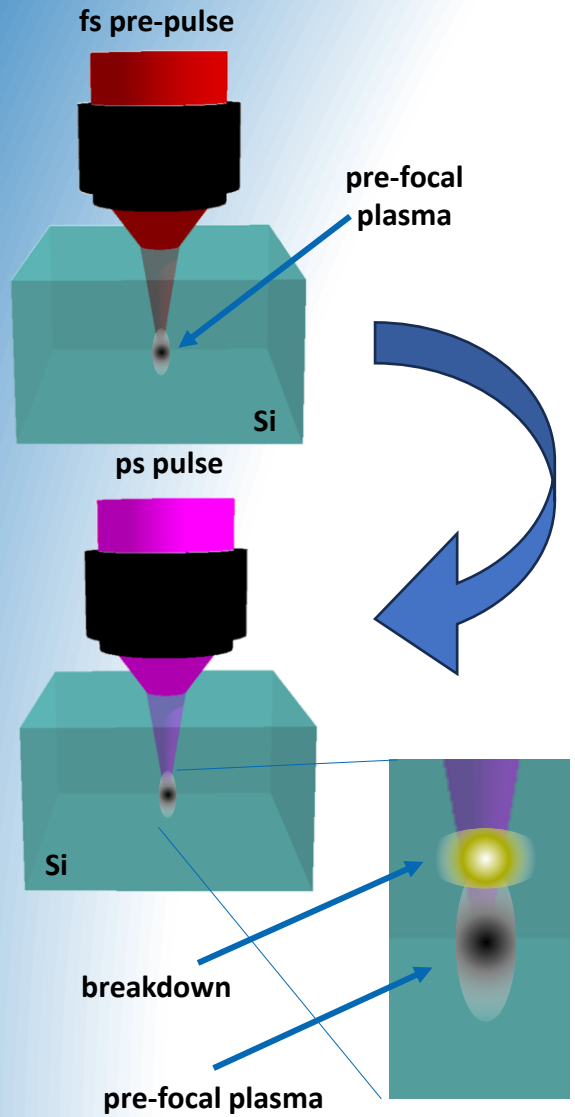


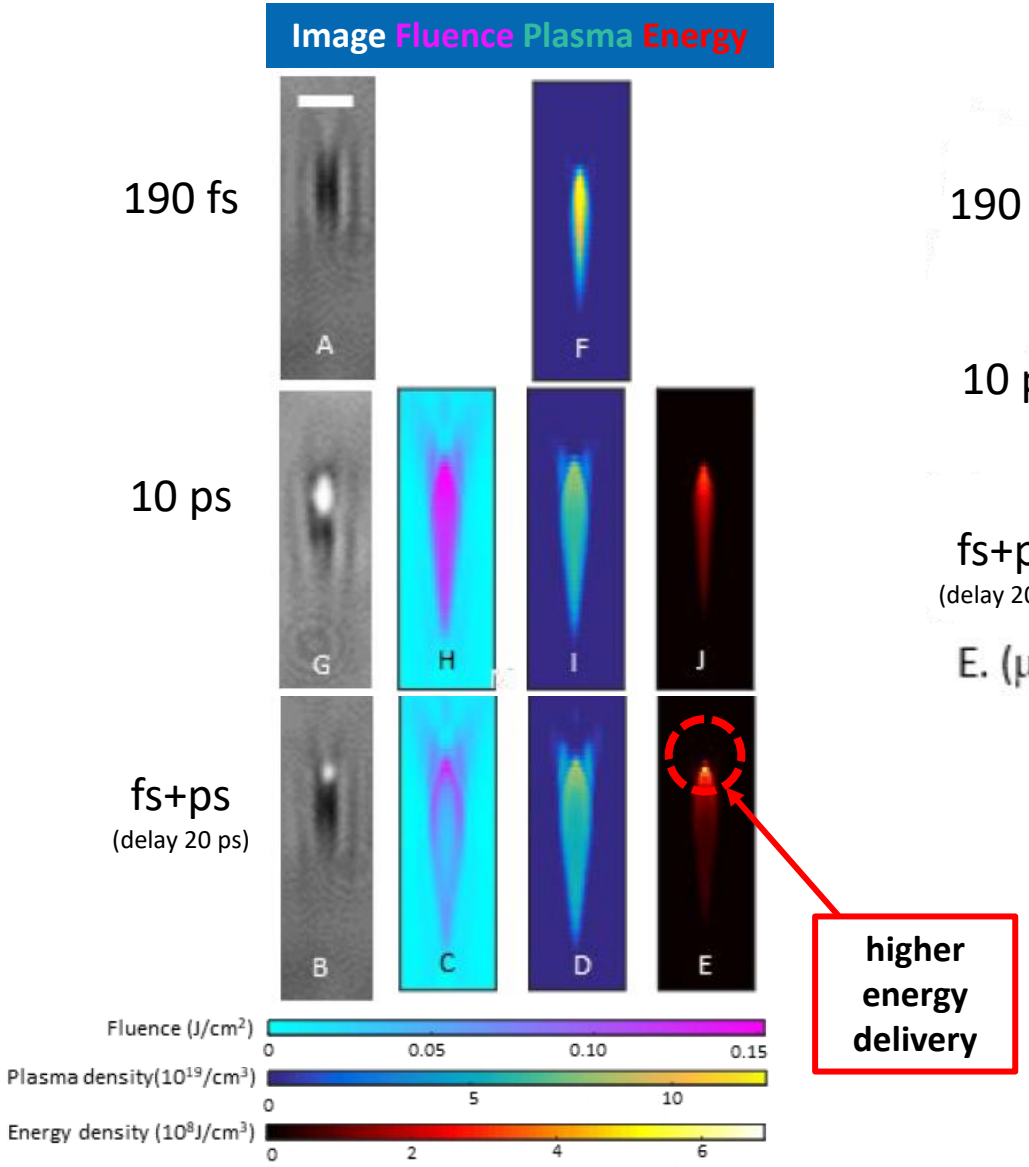
1 pulse (E●)
8 pulses (P●)
64 pulses (S●)

Pulse number = energy focus

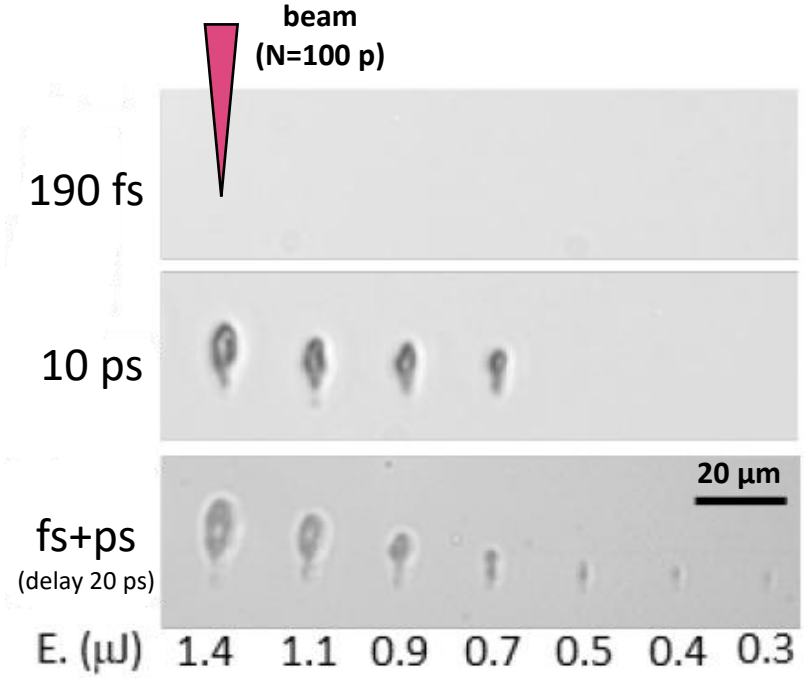
fs-ps double-pulse irradiation

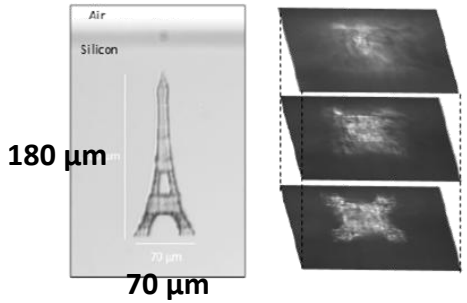
A. Wang, A. Das, V.Y. Fedorov, P. Sopeña, S. Tzortzakis, D. Grojo, In-chip critical plasma seeds for laser writing of reconfigurable silicon photonics systems, Nat Commun 16, 6733 (2025)





higher energy delivery





Motivation

Dielectrics

Silica (SiO_2)

- Bandgap: 9.0 eV
- n: 1.45

Scattering materials

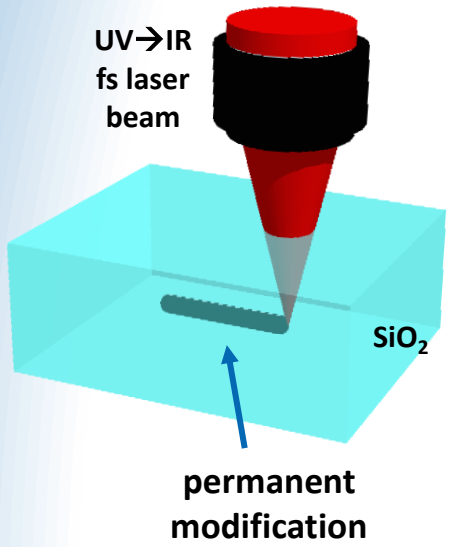
Polycrystalline ceramics

- Bandgap: ~5 eV
- n: 1.8

Granular polymers

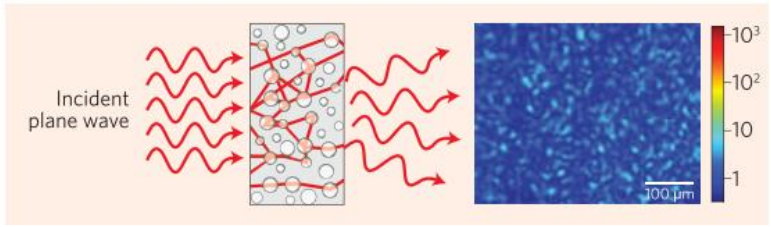
Ultrashort pulses in dielectrics

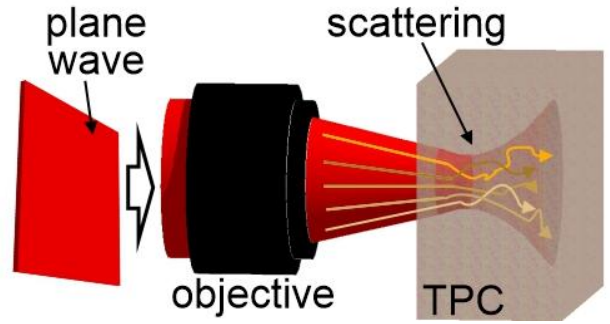
- Femtosecond pulses (~ 10^{-13} s)
- Extreme intensities (~10^{15} W/cm^2)
- Multiphoton absorption



Heterogeneous structure

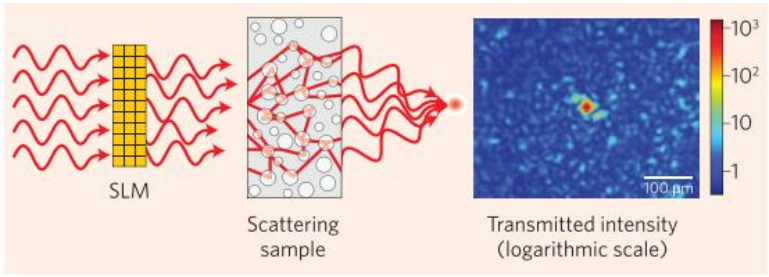
→ **Random light propagation**

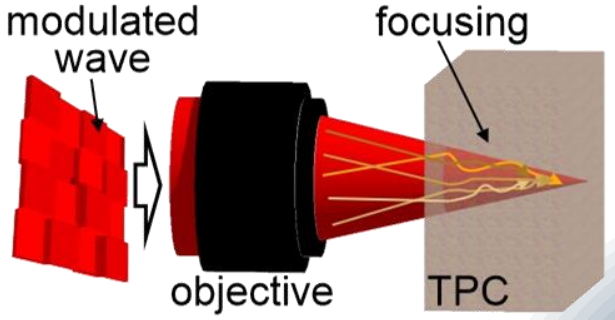




NO MODIFICATION

Phase compensation

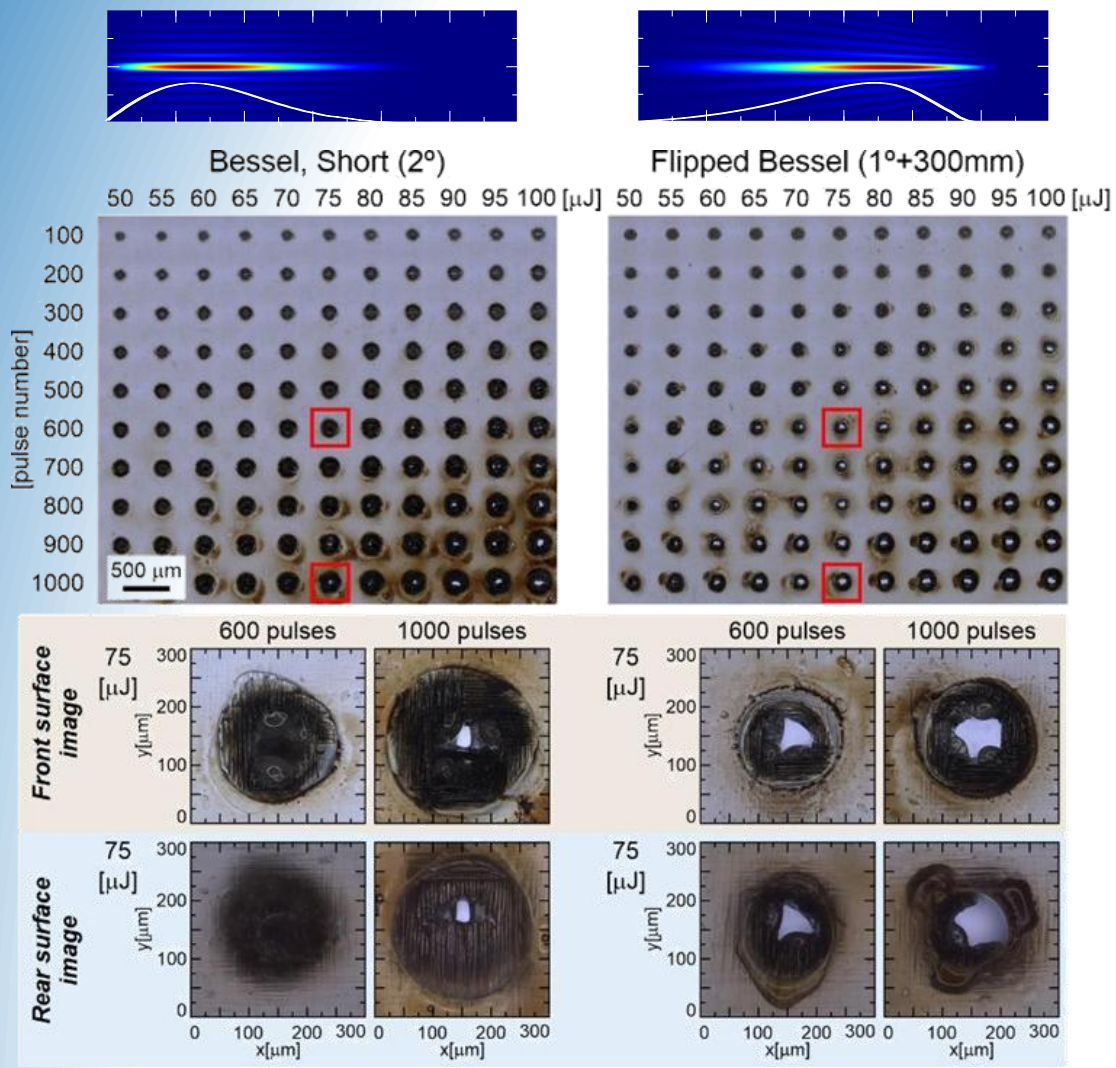


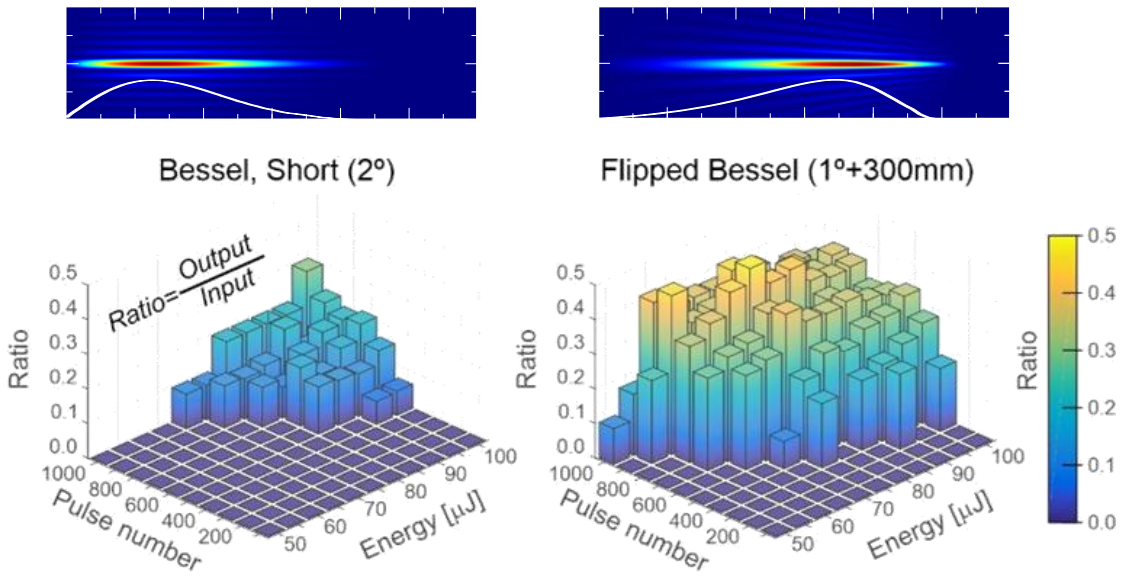


MODIFICATION

Flipped quasi-Bessel beams

P. Sopeña, N. Sanner, Customized flipped quasi-Bessel beams for infrared ultrafast laser drilling through scattering FR4 composite, Opt Laser Technol 192, 114037 (2025)





→ **Customized Bessel beams**

→ **Improve drilling by inverting on-axis profile**

→ **Next: Wavefront shaping**