Ultrafast laser processing of materials in environmental and biological sciences

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25 – 28 February 2024. Varadero, CUBA

CONAHCYT
CONSEJO NACIONAL DE HUMANIDADES
CIENCIAS Y TECNOLOGÍAS

ULTRASHORT PULSE LASERS
AND PROCESSING OF MATERIALS

CICESE

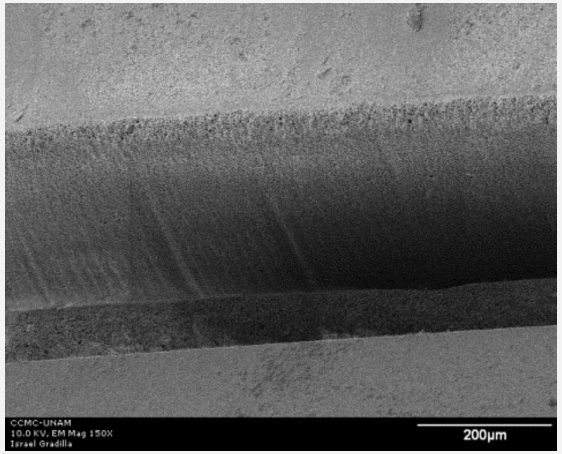
Outline

- Briefing on laser processing of materials
- Types of lasers for processing of materials
- Absorbing materials - Thermal processes
- Transparent materials – Ionization
- Laser micro/nanotexturing of surfaces
- Laser-induced caviation
- Final remarks

Laser processing of materials… what does it mean?

The laser processing of materials is the field of physics which focuses on the laser-matter interactions, aiming to understand the effects of the interaction on the material. As a result of the laser exposure, we could see some of the following:

Laser ablation. Material is expelled from the surface of the sample leaving a hole behind; it leads to laser micromachining.



Laser shaping of the refractive index. In transparent materials it is possible to laser-induce a refractive index increase or decrease; it leads to waveguide formation.

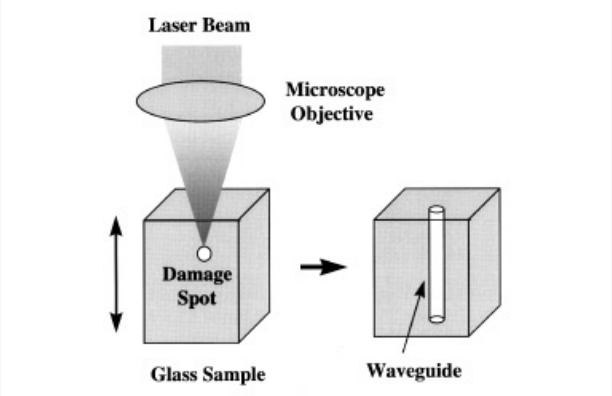
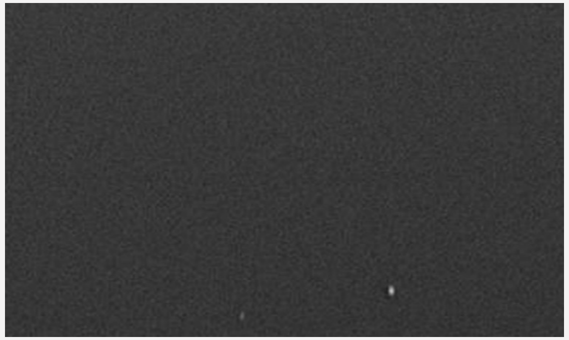
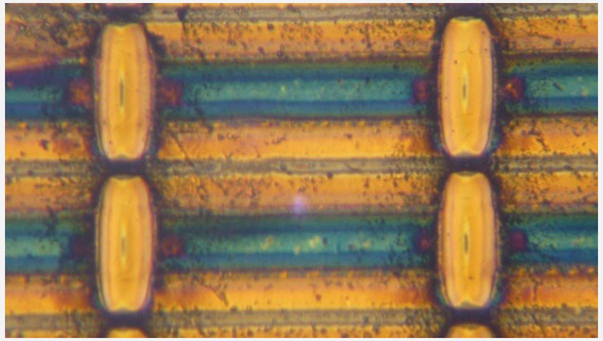


FIG. 2. Schematic diagram of optical waveguide writing by high repetition laser pulses.

[Laser-induced material transformation.]() In several materials it is possible to laser-induce a dramatic change in the material features including their structure (crystalline, amorphous), stoichiometry, surface morphology, etc.; which leads to the modification of the optical, electrical, chemical and thermal properties.





[Laser-bio interactions.]() Lasers are capable of selectively interacting with bio-specimens; this leads to biological and medical applications of lasers.

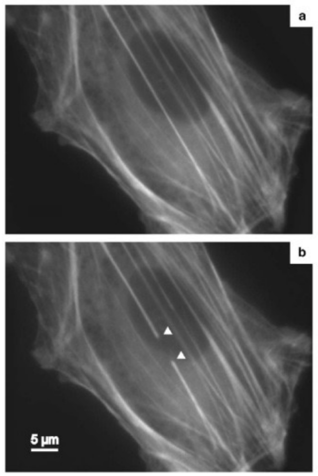
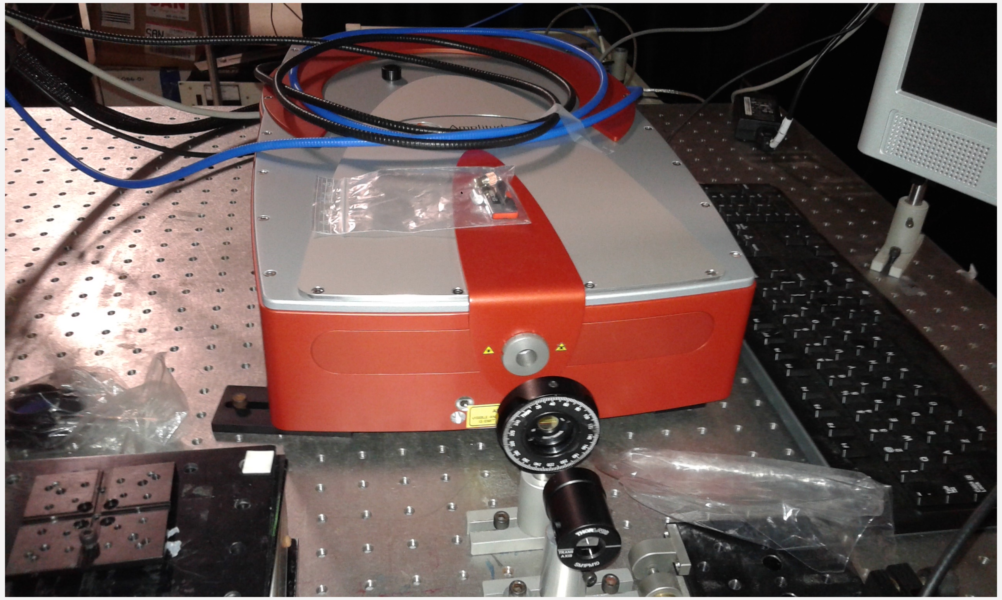
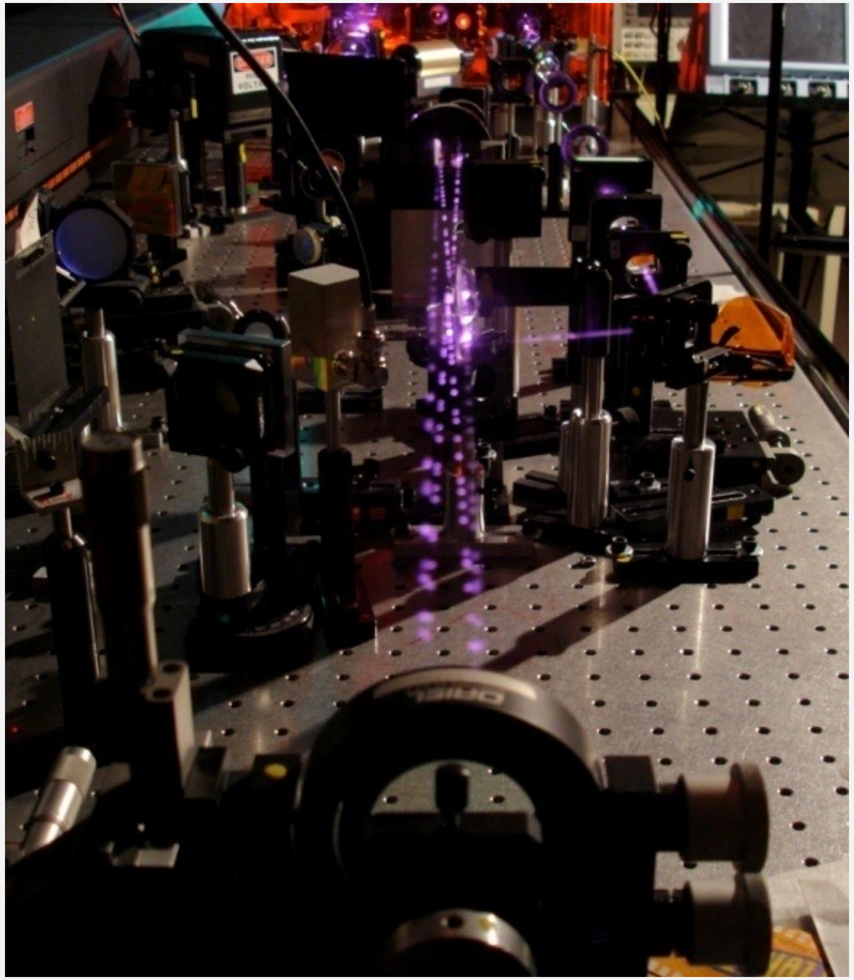


Fig. 8. Fluorescence microscope images of the YFP-labeled actin network in an endothelial cell (a) before and (b) 4 s after laser dissection of an actin fiber bundle. The triangles show the retracting ends of the bundle.

Lasers and materials meet to give place to a very interesting collection of fundamental and applied problems and challenges.

- Micro and nano-structuring of all sort of materials
- Direct laser writing waveguides in transparent materials
- 3-D patterning
- Materials physical and chemical properties modification
- Laser-biotissue interactions
- etc.





Types of lasers

Pulsed *vs* continuous wave (cw) lasers:

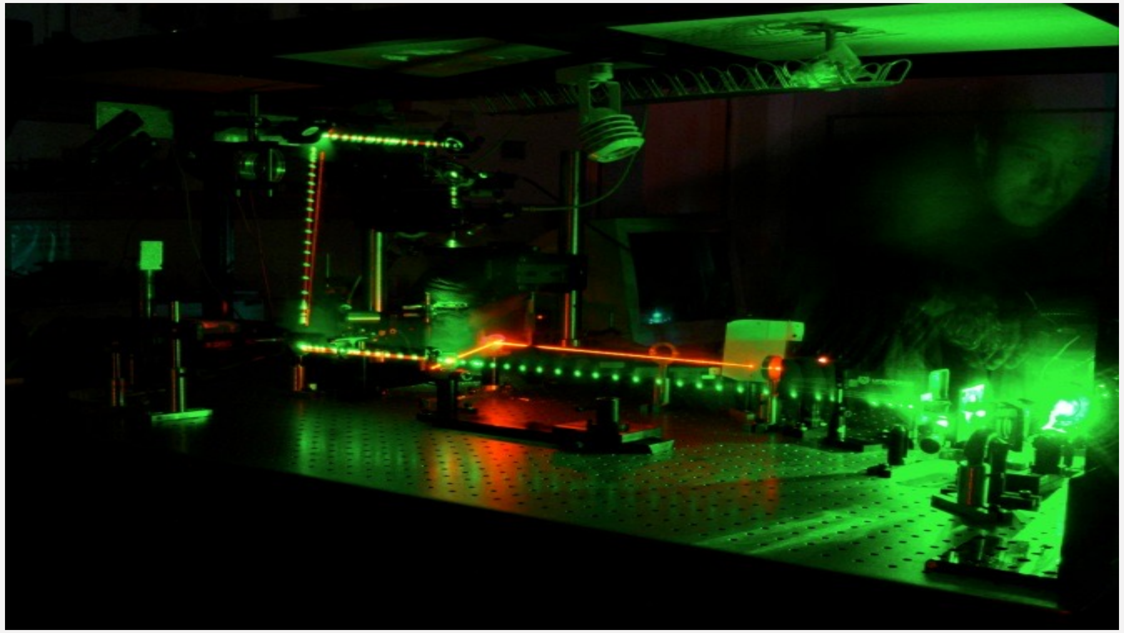
- **Pulsed lasers:**

  Long (ms, μs) to ultrashort pulses (femtosecond, attosecond)

  Wide range of wavelengths from UV to NIR

  High fluence, peak power and irradiance even for low per pulse energy

$$F = \frac{E_p}{A} ; P = \frac{E_p}{\tau_p} ; I = \frac{E_p}{A * \tau_p}$$



  Tunable repetition rate

- **CW laser:**

  Wide range of wavelengths from UV to NIR

  High energy, moderate average power, and high fluence and irradiance possible if very tight focusing is used

  Long exposures

Typical pulsed lasers for processing of materials

- Excimer

  λ = 193, 308 nm, τ ~ 1 ns, E_P ~ mJ, Hz

- Nd:YAG

  λ = 1064, 532, 355 nm, τ ~ 5-100 ns, E_P ~ mJ, Hz-kHz

- Nd:glass

  λ = 1053 nm, τ ~ 1-10 ps, E_P ~ μJ, Hz-kHz

- Ti:sapphire

  λ = 780-840 nm, τ ~ 50-200 fs, E_P ~ nJ, kHz-MHz

- Yb fiber based

  λ = 1030 nm, τ ~ 250 fs – 10 ps, E_P ~ nJ, MHz

Fundamental physics on the laser processing of materials

Thermal physics

Heat produced by the laser pulse train

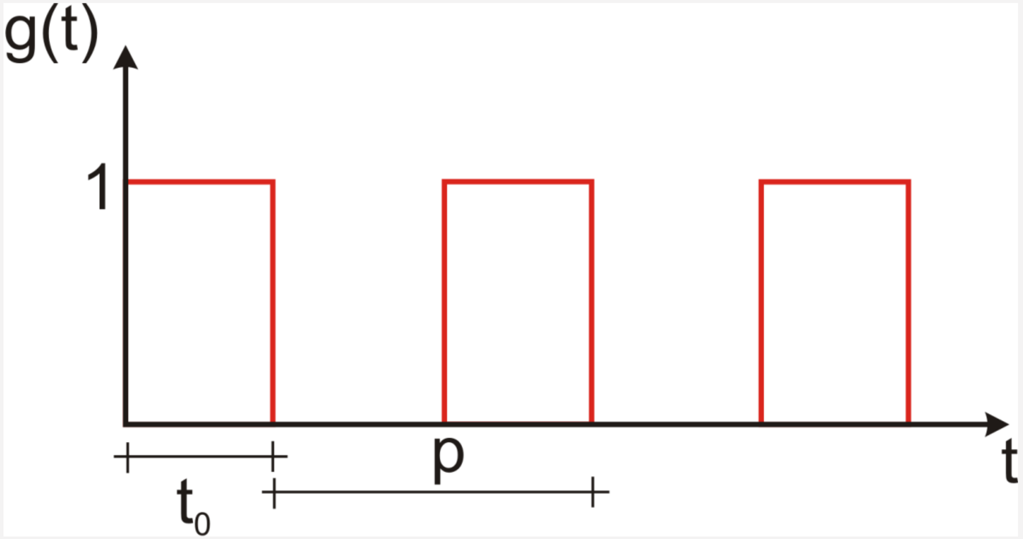
The power density transferred to the sample by optical absorption

$$Q(r,t) = \alpha I(r,t) = \alpha \frac{2E_0 e^{-2r^2/R^2}}{\pi R^2 t_0} g(t)$$

α = Absorption coefficient [cm^{-1}]
I = Irradiance [W/cm^2]
R = Radius of laser beam
E_0 = Incident energy per pulse
t_0 = Temporal pulse width
$g(t)$ = Temporal distribution of pulse train

J. A. Sell, Photothermal investigations of solids and fluids. (Academic Press, London, 1989)

Temporal distribution of the laser pulse train



$$g(t)=\sum_{m=0}^{M-1}[H(t-mp)-H(t-(mp+t_0))]$$

M = Total number of pulses in the train
$H(t)$ = Unit step function
m = number of pulses
p = period

Heat diffusion equation

$$\frac{\partial T(r,t)}{\partial t} = D\nabla^2 T(r,t) + \frac{1}{\rho C_p} Q(r,t)$$

T = Temperature
D =Thermal diffusivity
r = density
C_p = specific heat at constant pressure

Boundary conditions

$$T(r,t)\Big|_{t=0} = 0 \qquad T(r,t)\Big|_{r=\infty} = 0 \qquad \frac{dT(r,t)}{dr}\Bigg|_{t=0} = 0$$

Temperature change due to M laser pulses

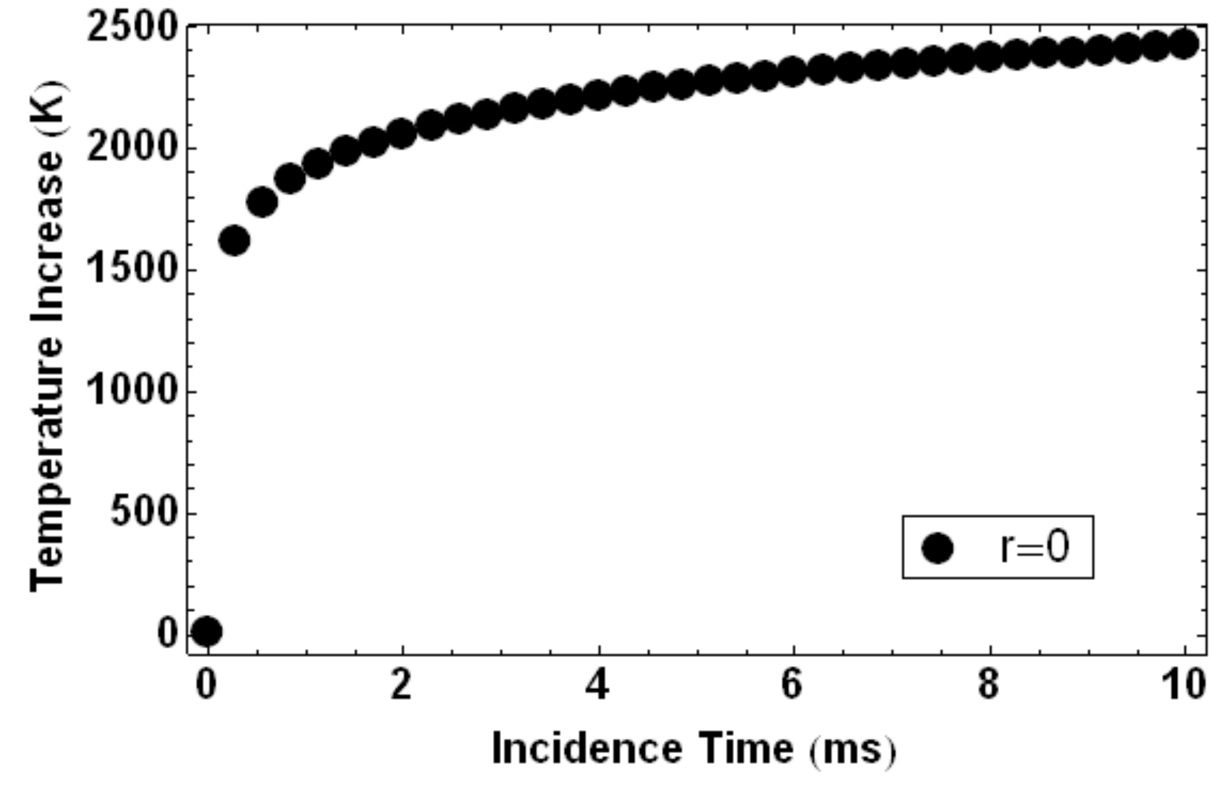
$$T(r,t)=\frac{2\alpha E_0}{\pi R^2\rho C_p}\sum_{m=0}^{M-1}\frac{1}{\left[1+\frac{2(t-mp)}{t_c}\right]}\mathrm{Exp}\left[\frac{-2r^2}{R^2\left(1+\frac{2(t-mp)}{t_c}\right)}\right]\quad \text{for}\quad t\geq(M-1)p$$

with $t_c=\frac{R^2}{4D}$ $\quad R=1.9\,\mu\text{m}$, $D=0.011\,\text{cm}^2\text{s}^{-1}$ $\quad t_c=0.8\,\mu\text{s}$

t_c = Characteristic thermal diffusion time

Temperature reached on YSZ during laser irradiation

60 fs lasers pulses at 800nm, up to 5nJ per pulse, and a rep rate of 70MHz
focusing with an aspheric lens (NA=0.5)
fluence per pulse of ~ 30mJ/cm^2



Nonlinear optics and ionization physics

Multiphoton ionization and avalanche ionization

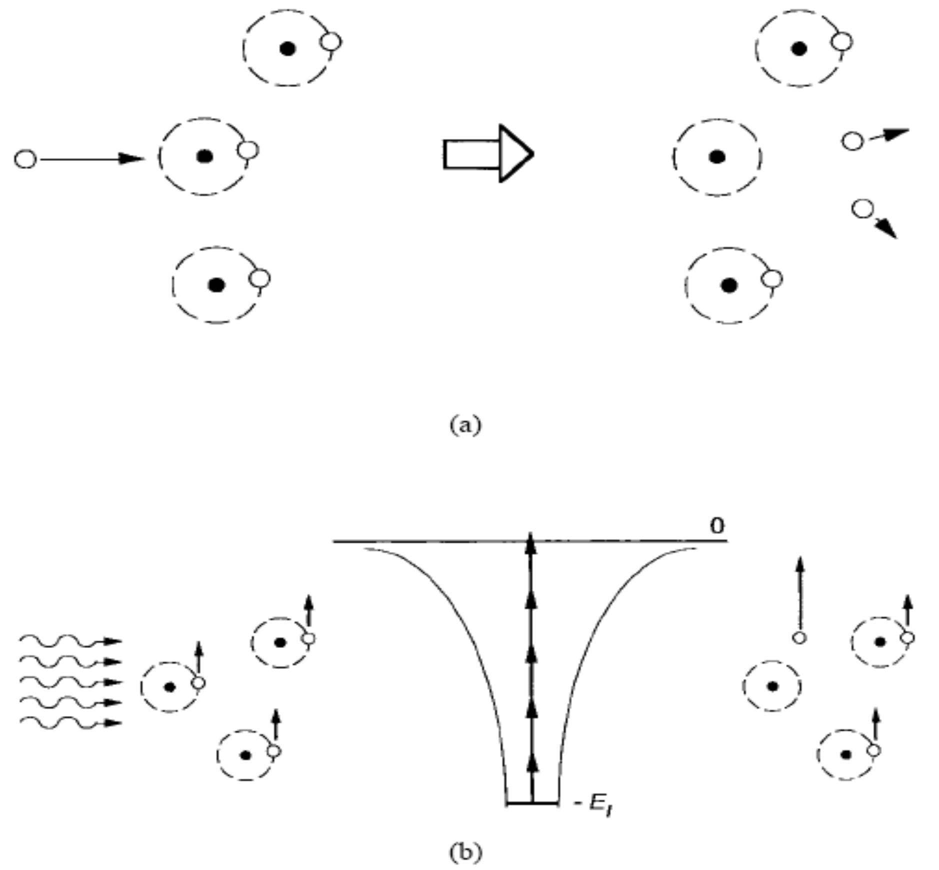


Fig. 1. (a) Schematic of electron avalanche by collisional impact ionization. Secondary free electrons are generated during collisions with electrons whose kinetic energy is greater than the bound electrons binding energy. (b) The multiphoton ionization process. The bound electron is ionized by simultaneously absorbing m photons.

X. Liu, D. Du, and G. Mourou. *IEEE J of Quantum ELectron*. **33**, 1706 (1997)

Multiphoton ionization and avalanche ionization

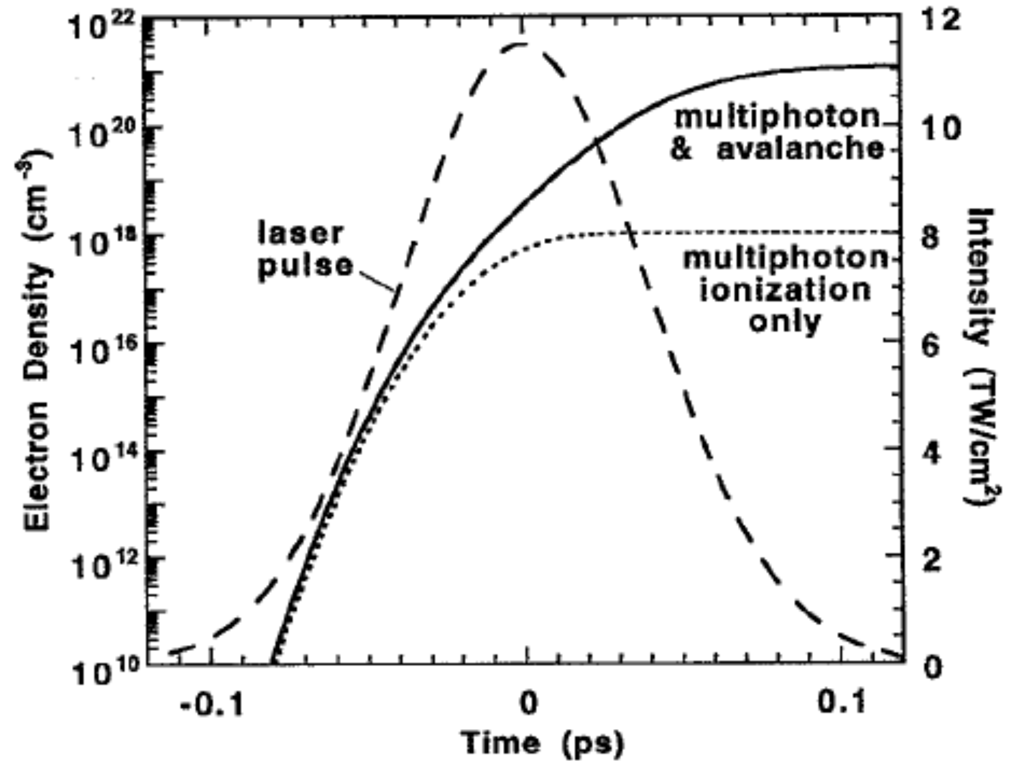
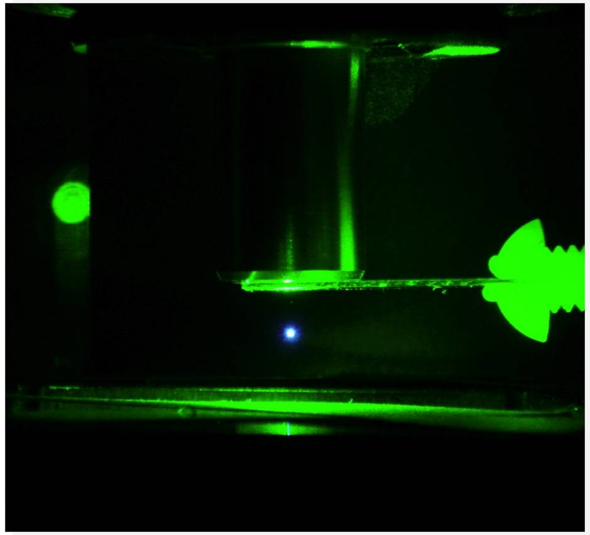


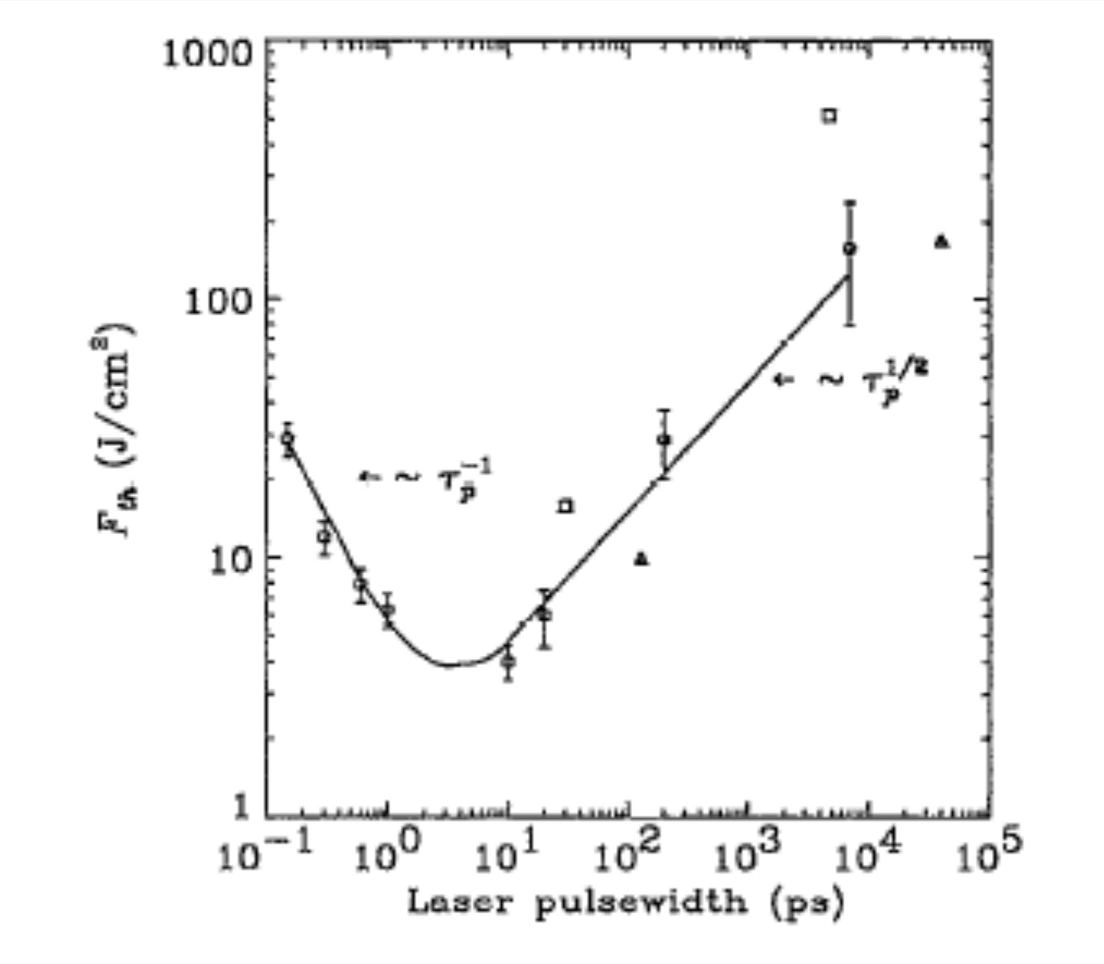
FIG. 3. Calculated evolution of free electron density for a 100 fs, 1053 nm pulse (dashed curve) of peak intensity 11.7 TW/cm^2 in fused silica. Multiphoton ionization (dotted curve) starts the avalanche; solid curve is total electron density including impact ionization.



B. C. Stuart, M. D. Feit, S. Herman, A. M. Rubenchik, B. W. Shore, and M. D. Perry, *JOSA B* **13,** 459 (1996)

Physics changes below 10 ps

Threshold laser ablation of glass vs τ_p



D. Du, X. Liu, G. Korn, J. Squier, G. Mourou. *Appl. Phys. Lett*. **64**, 3071 (1994)

Time-resolved physics

Damage for long laser pulses and damage suppression for ultrashort laser pulses

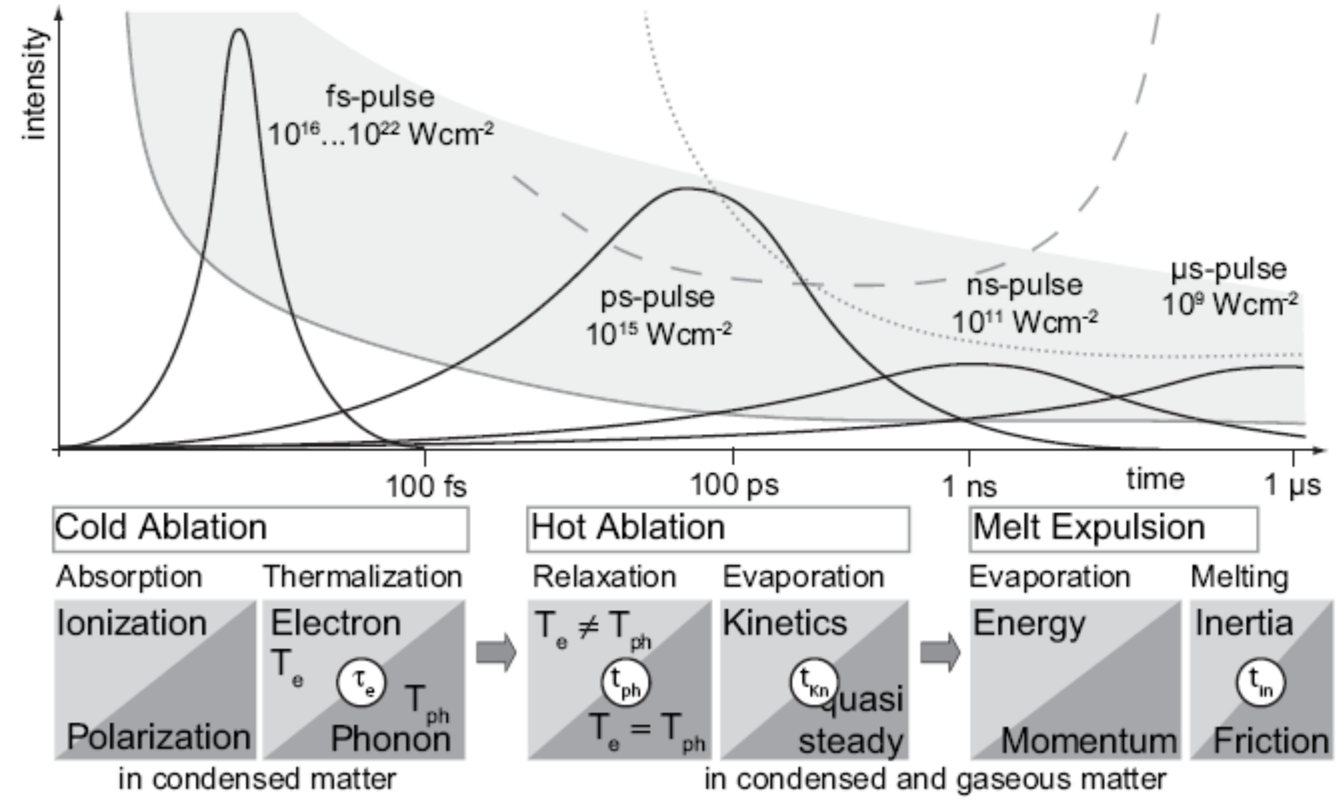
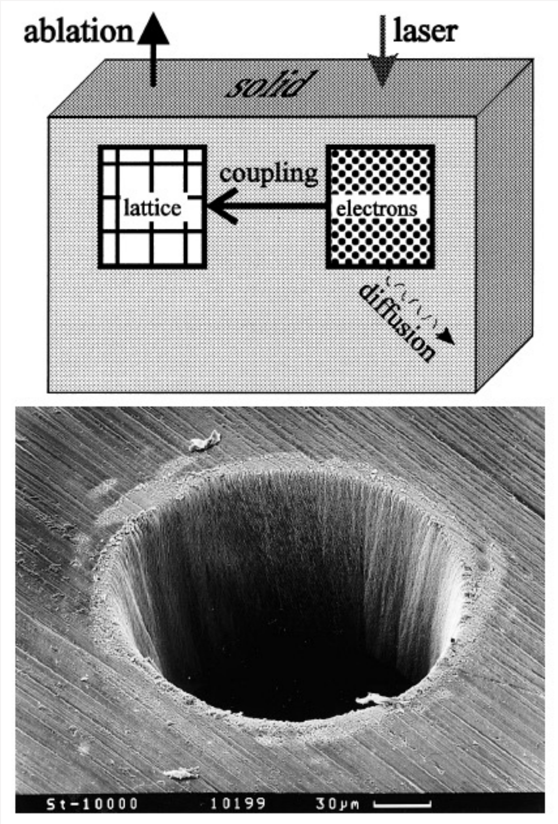
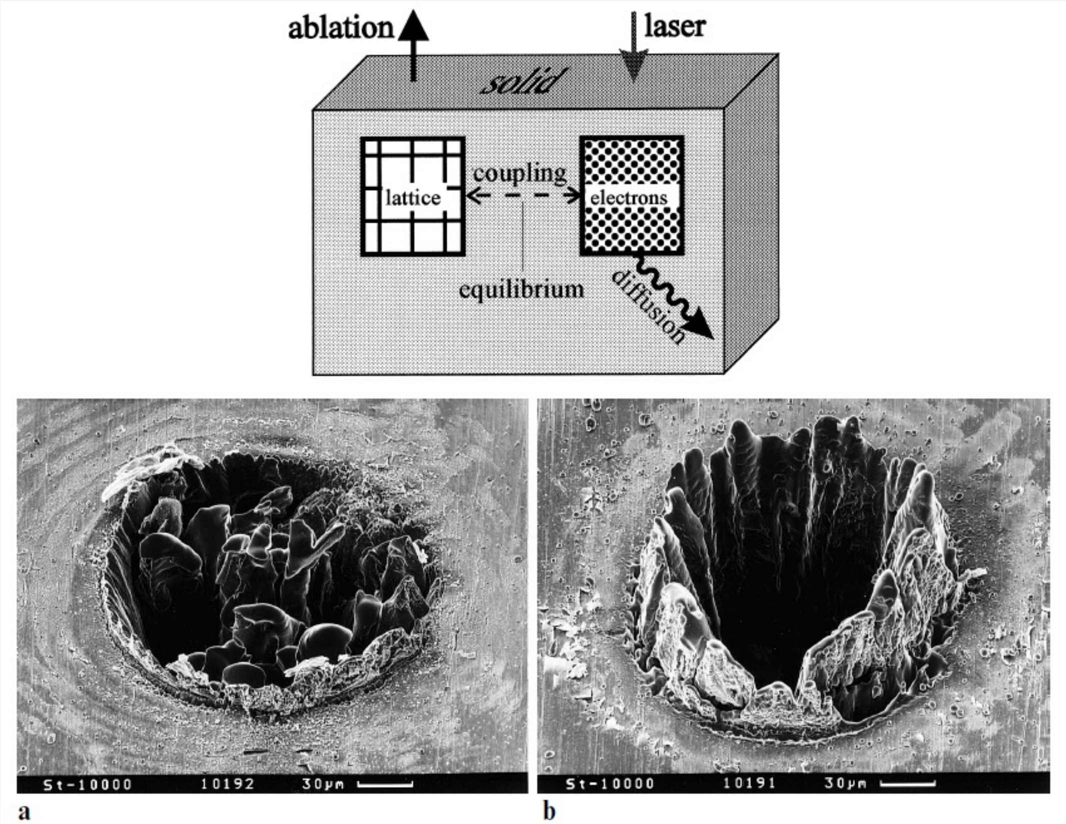


Fig. 5.4. Mapping of the three different physical domains – Cold Ablation, Hot Ablation and Melt Expulsion – with respect to the corresponding time scales. The

The theory of laser materials processing. Springer series in Materials Science 119, Ed. J. Dowden (2009). p 135

Laser ablation on the same material, why does it look so different?





200 fs, F = 0.5 J/cm²

80 ps, F = 3.7 J/cm²

3.3 ns, F = 4.2 J/cm²

B. N. Chichkov, C. Momma, S. Nolte, F. von Alvensleben, A. Tünnermann, *Appl. Phys. A* **63,** 109 (1996)

Two-temperature model

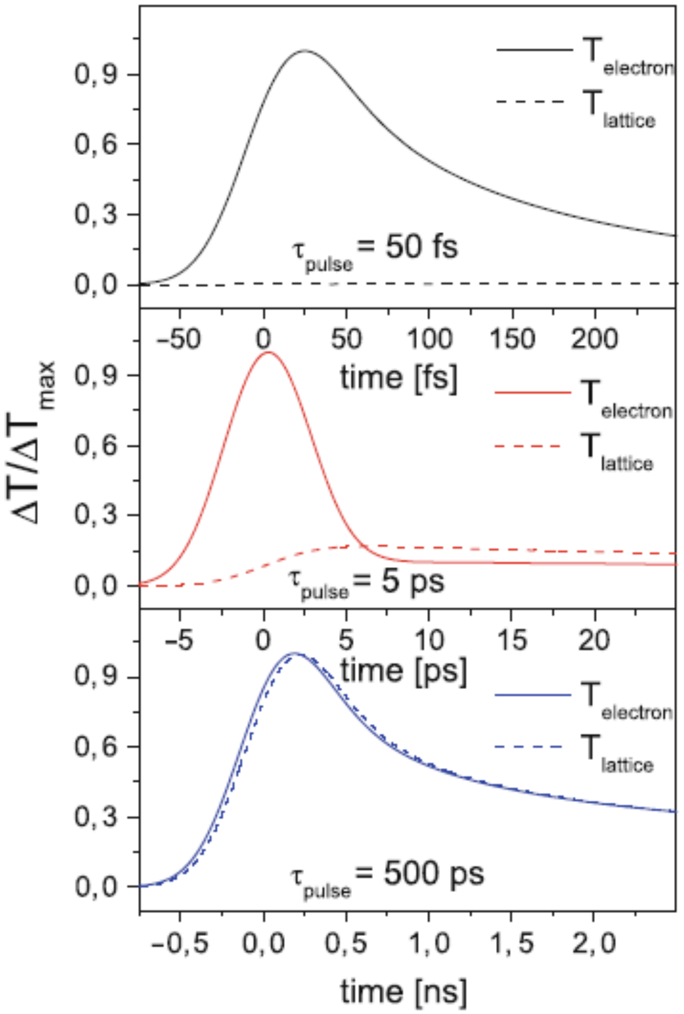
$$C_e \frac{\partial T_e}{\partial t} = \nabla(k_e \nabla T_e) - H(T_e, T_L) + S(t)$$

$$C_L \frac{\partial T_L}{\partial t} = H(T_e, T_L)$$

B.L. Kapeliovich, S.I. Anisimov, T.L. Perel'man, Sov. Phys. JETP 39, 375 (1975)

Electron-electron and electron-phonon interaction

Fig. 3.1 Electronic and lattice temperature profiles (simulations obtained with the TTM) in cupper irradiated by laser pulses of different durations (ranging from 50 fs to 500 ps). With 50 fs pulses, electrons and lattice are completely decoupled and the lattice is substantially unaffected by the laser beam. With 500 ps pulses, electron and lattice follow almost identical temperature evolutions



Laser processing of materials. Springer series in Materials Science 139, Ed. P. Schaaf (2010). p 26.

Advantages of using lasers in medicine

- Energy deposition: well controlled, and both spatial and time confined

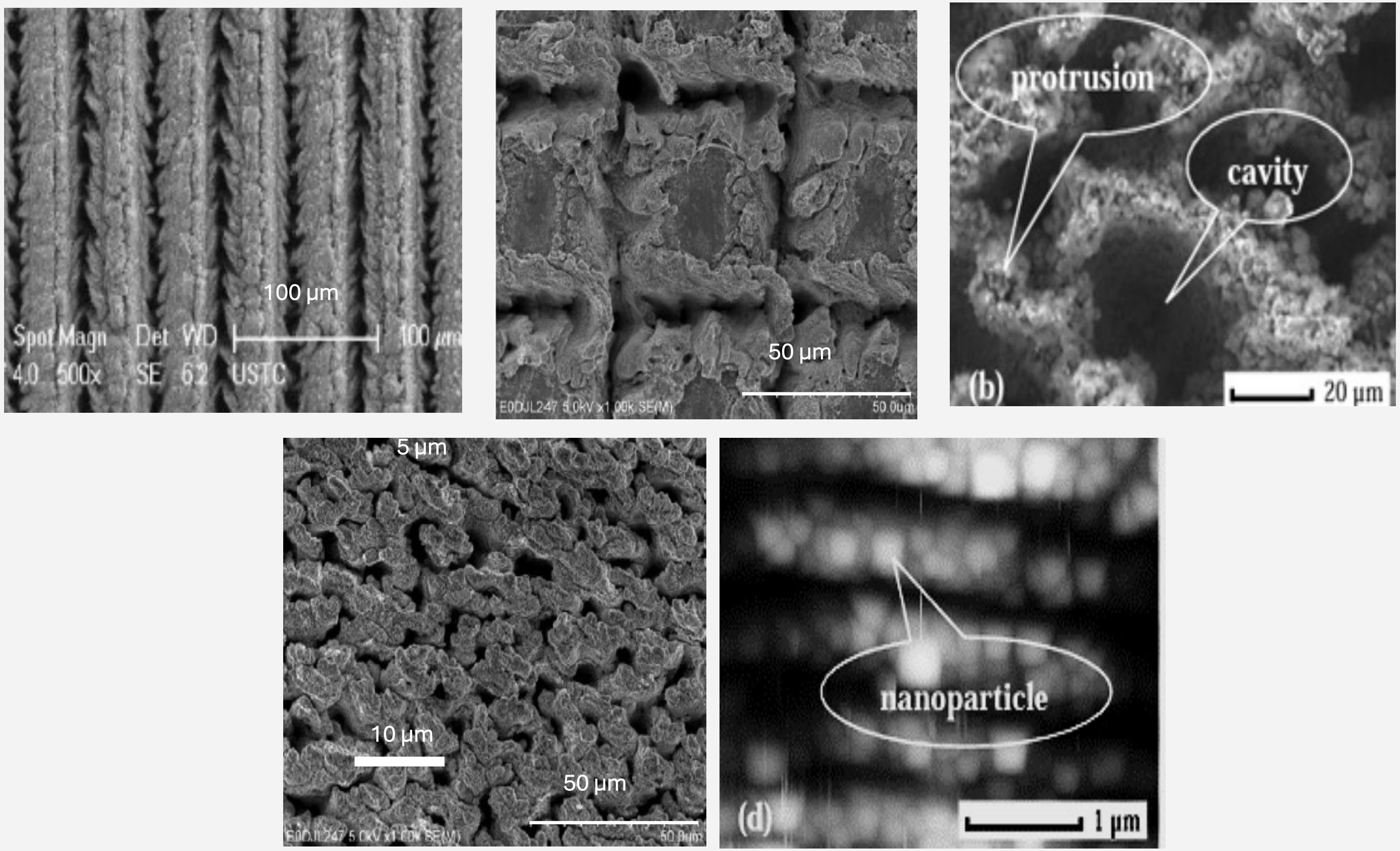
- Optical selectivity in tissue

- Time exposure shorter than characteristic heat diffusion in biomaterials

Laser micro & nano surface texturing

- **Direct Laser Ablation:**. Material removal in the laser ablation process is due to the production of nanoparticles upon heating and melting the targeted material with the irradiated laser pulse.

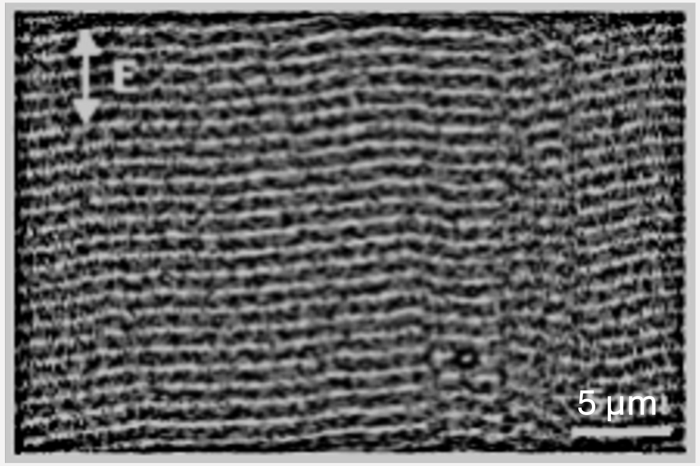
Applied surface science ***276****, 203-209 (2013).*

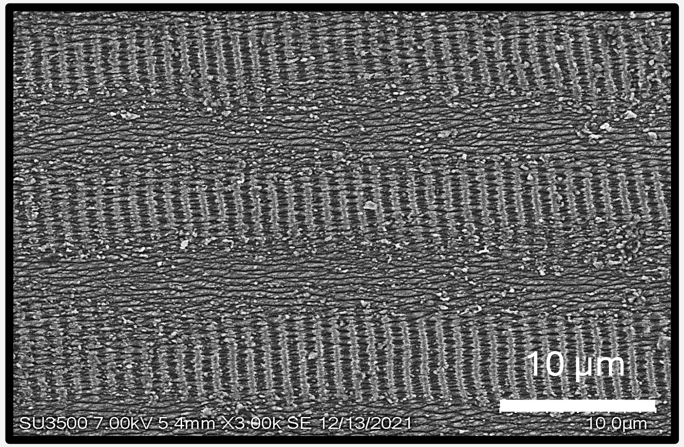


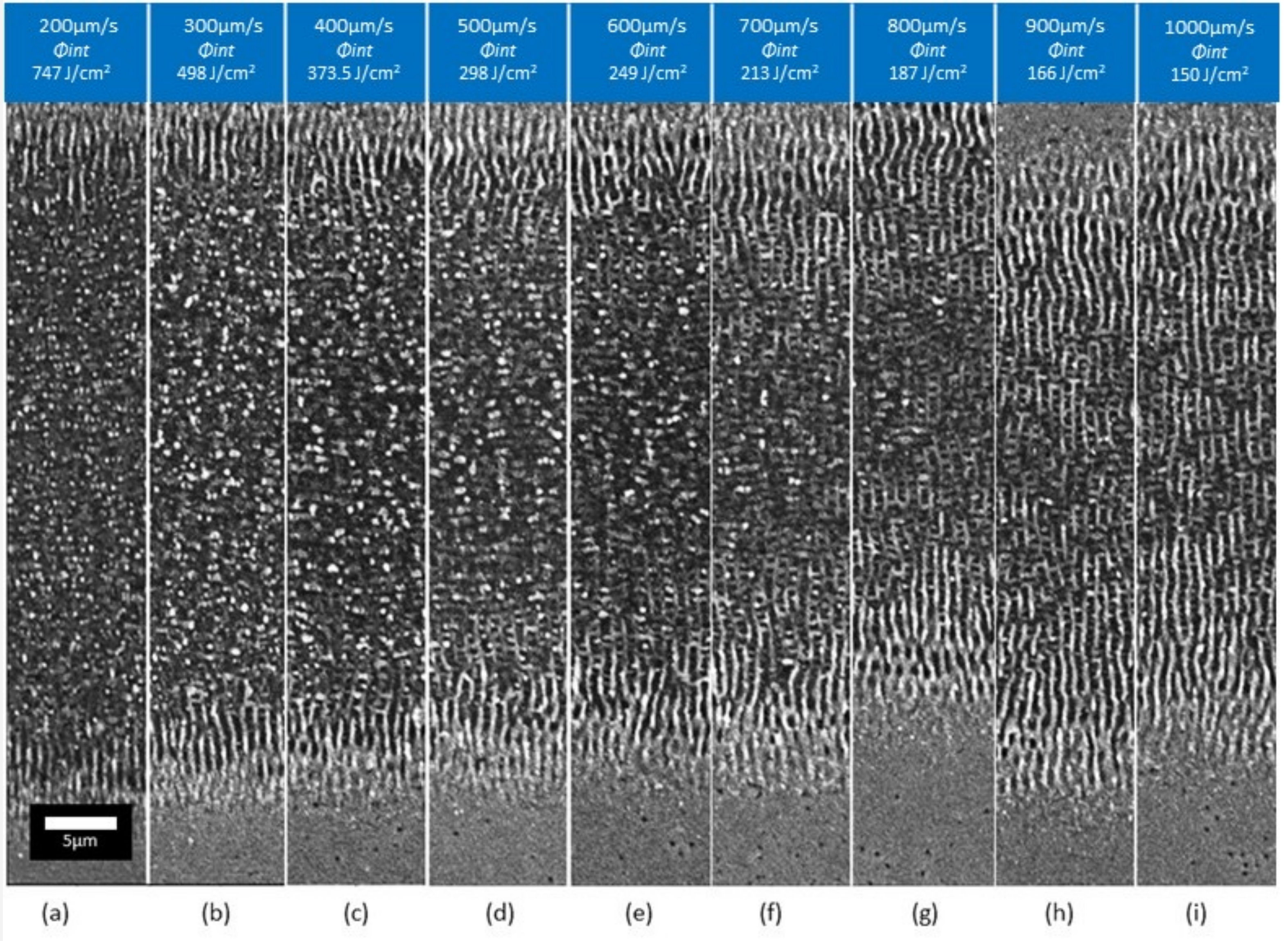
- **Laser Induced Periodic Surface Structures (LIPSS):** self-organized micro- and nanostructures formed on the surfaces of solid material by irradiation of linearly polarized laser radiation.

Applied Surface Science ***606*** *,154762 (2022).*

Optical Materials Express ***11****, 2892-2906 (2021).*

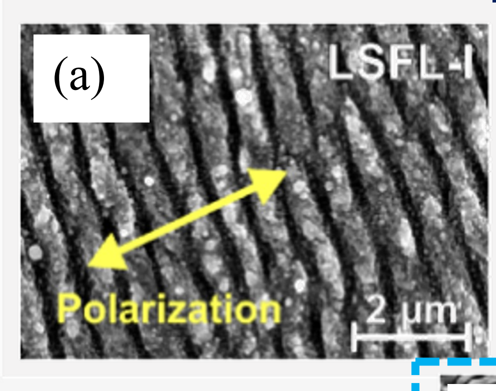






LIPSS

- Laser-induced Periodic Surface Structures.
- Universal phenomenon.
- Quasi-periodic lines.
- Simple single-step process

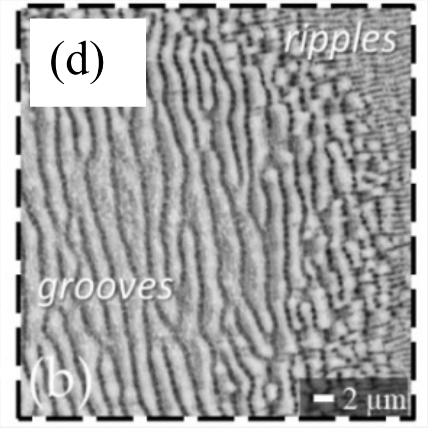


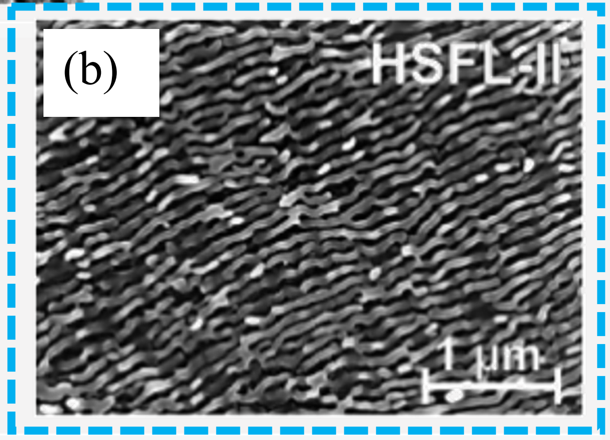
a) Low spacial frequency LIPSS $\lambda/2 \le \Lambda_{LSFL} \le \lambda$.

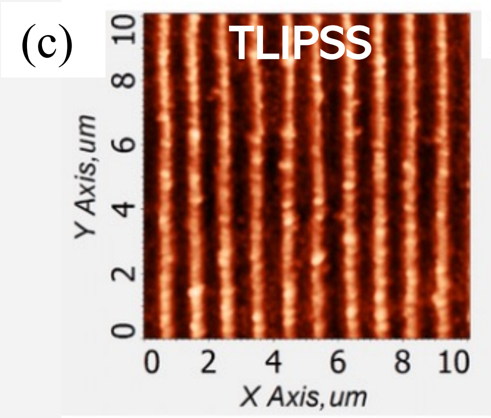
b) High spacial frequency LIPSS $\Lambda_{HSFL} < \lambda/2$

c) Termochemical LIPSS $\lambda/2 \le \Lambda_{TL} \le \lambda$

d) Suprawavelength LIPSS $\Lambda_{SL} > \lambda$



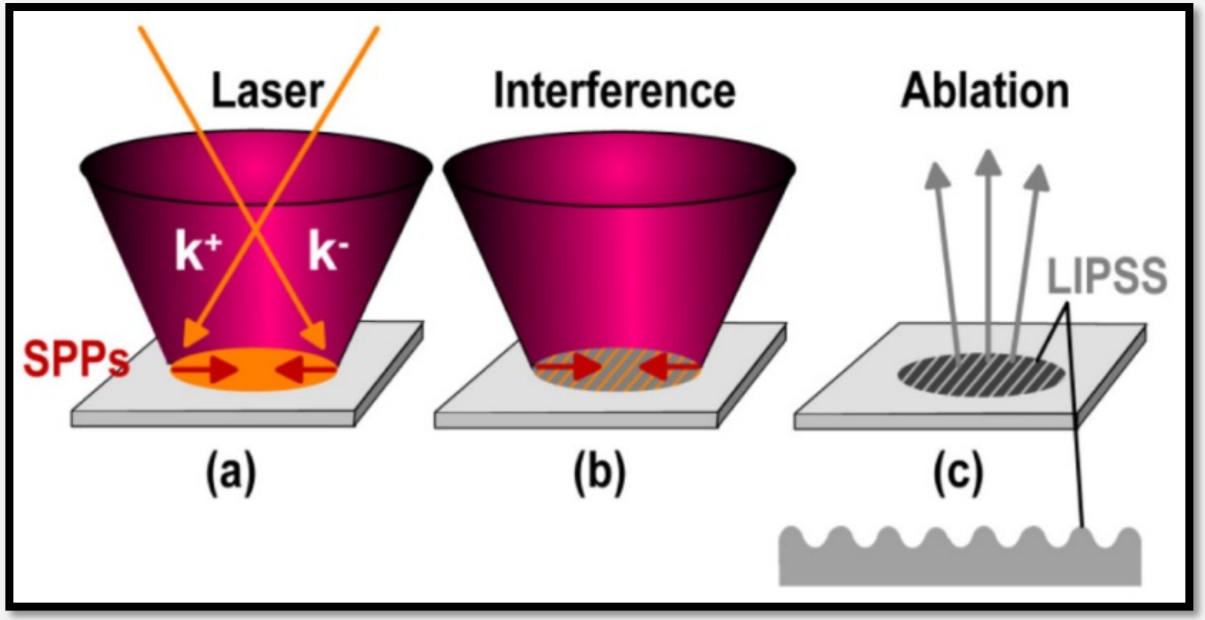




(a,b) J. Bonse, S. Höhm, S. V. Kirner, A. Rosenfeld and J. Krüger, IEEE Journal of Selected Topics in Quantum Electronics, **23**, 9000615, (2017).
(c) Dostovalov, A.V. & Korolkov, Victor & Terentiev, V. & Okotrub, K. & Dultsev, Fedor & Babin, Sergey. (2016).. 10.1109/PIERS.2016.7735797.
(d) Nivas JJ, Amoruso S.. Nanomaterials **11**, 174 (2021).

LSFL

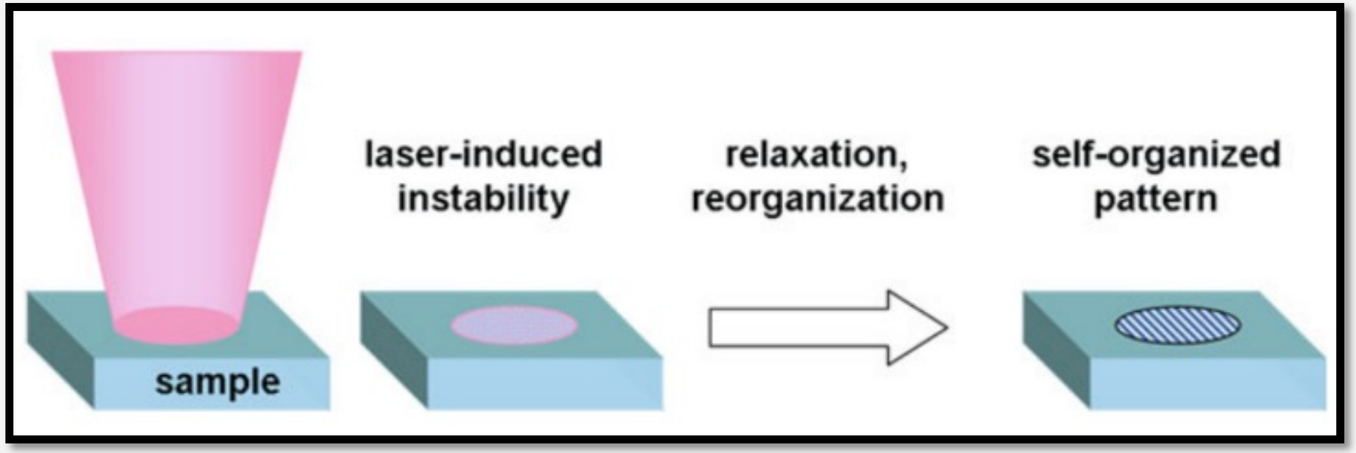
ELECTROMAGNETIC THEORIES



J. E. Sipe, et al. Physical Review B ***27****, 1141 (1983).*

HSFL

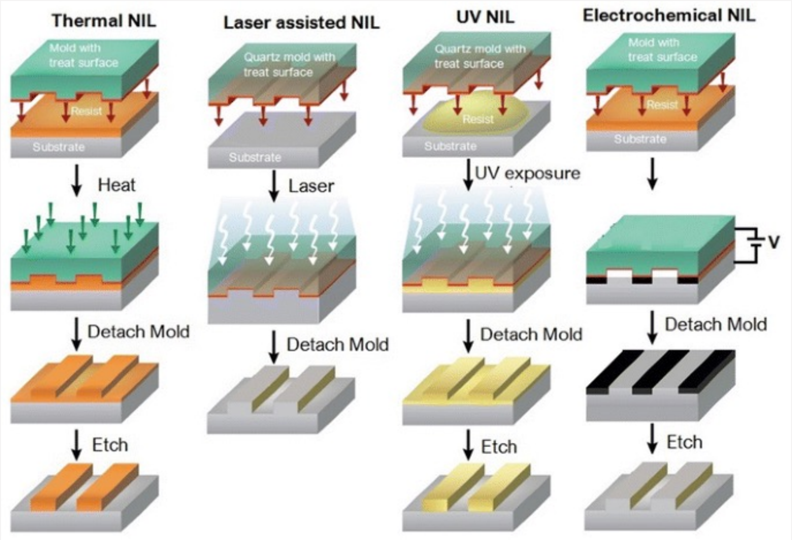
SELF-ORGANIZATION



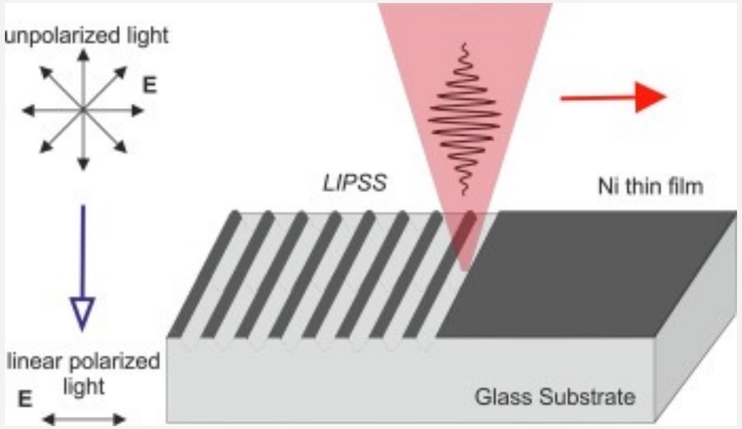
Olga Varlamova, et al. (2015). Springer International Switzerland, S. Sakabe et al. (eds.), Progress in Nonlinear Nano-Optics, Nano-Optics and Nanophotonics.

ADVANTAGES

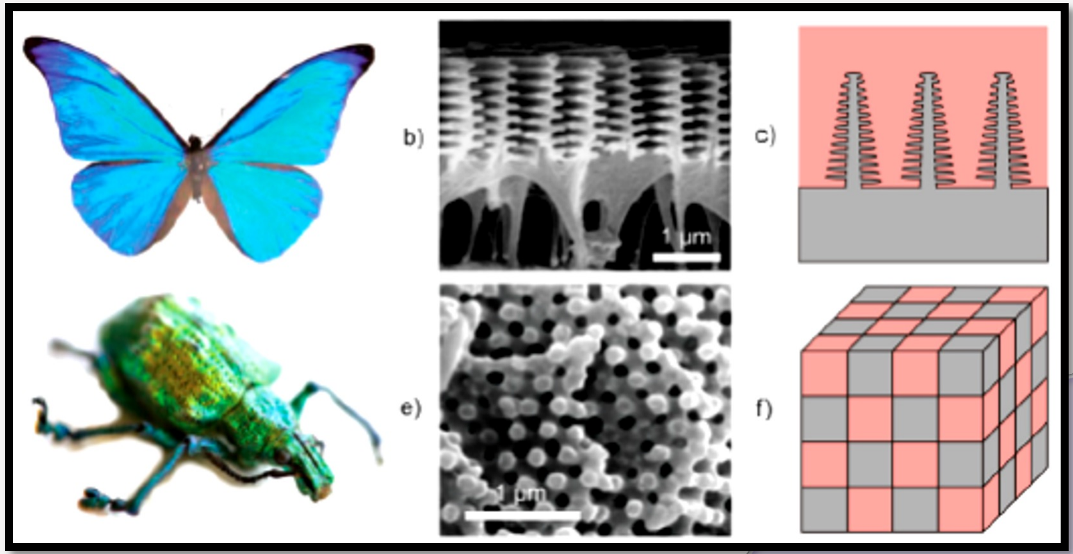
NANOLITOGRAPHY



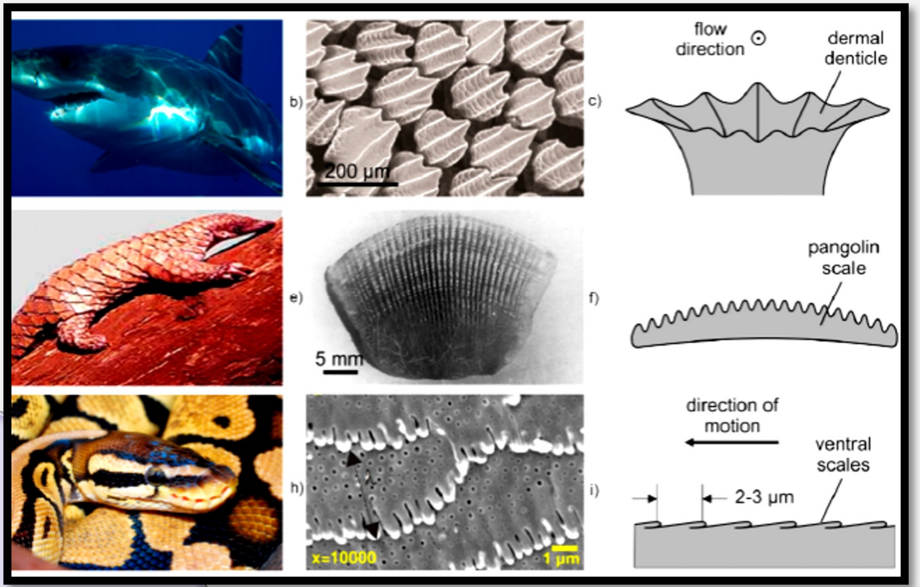
LASER TEXTURING



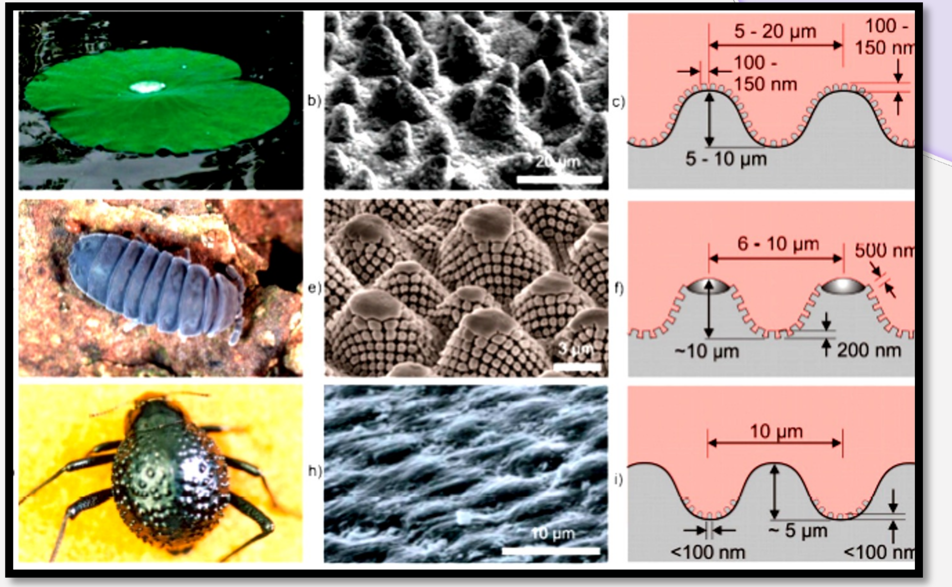
APPLICATIONS



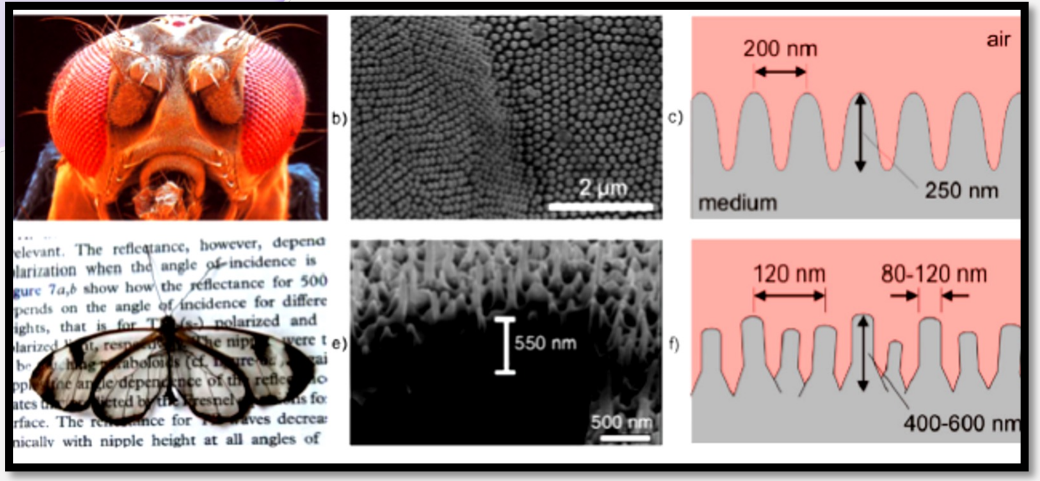
Coloring structures, Optical massive storage



Tribological applications



Hydrophobic applications

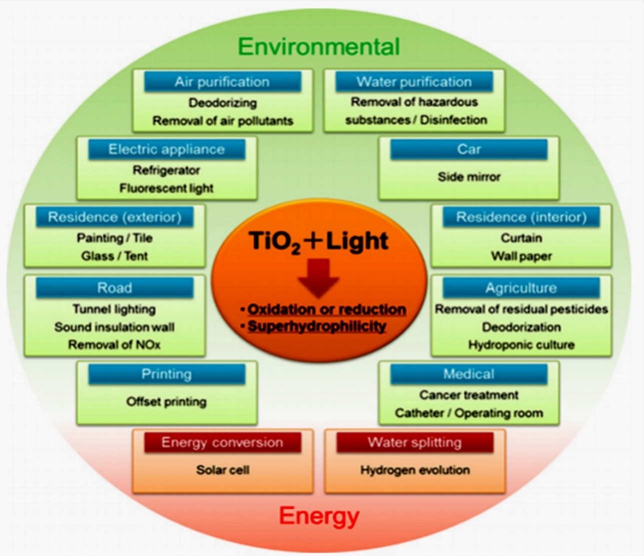


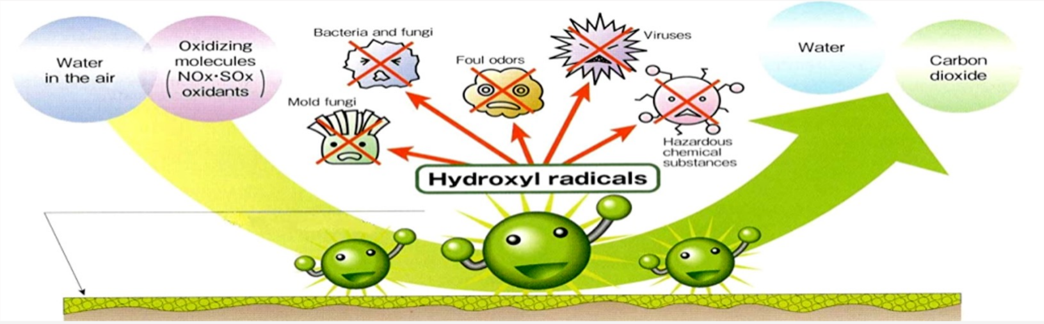
Antireflective surfaces

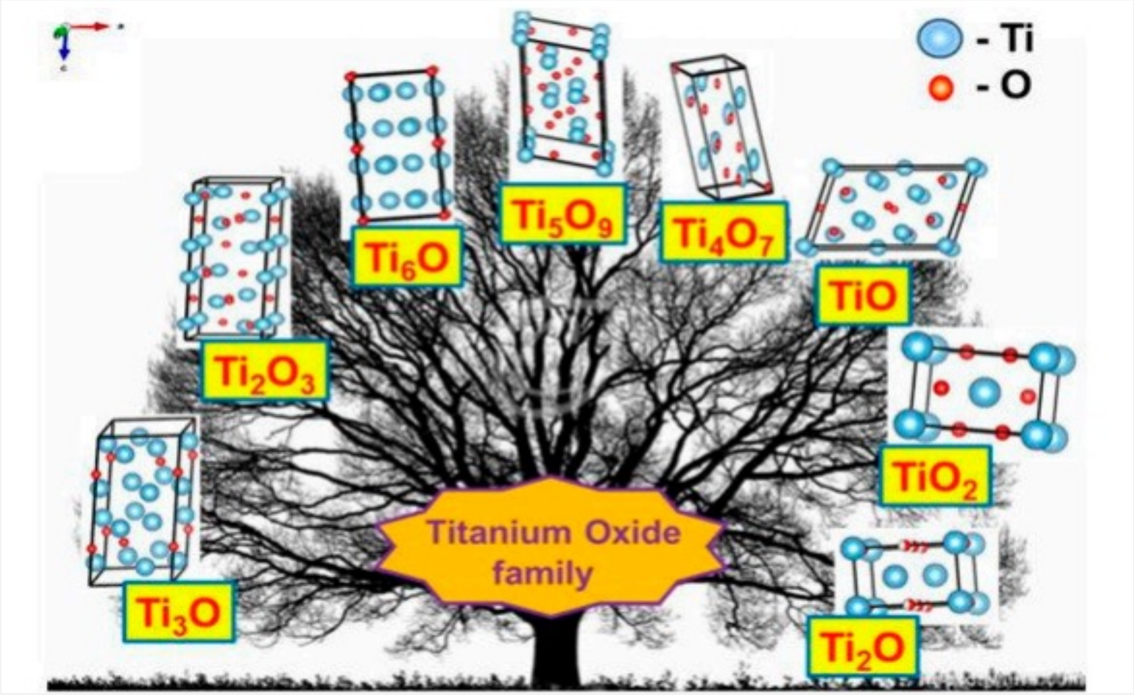
Muller, Kunz & Graf. Materials ***9****, 476 (2016).*

Photocatalysis / Gas sensors

TiO2 - biocompatible, photocatalytic, metamaterial (high refractive index and also refractive index near zero)



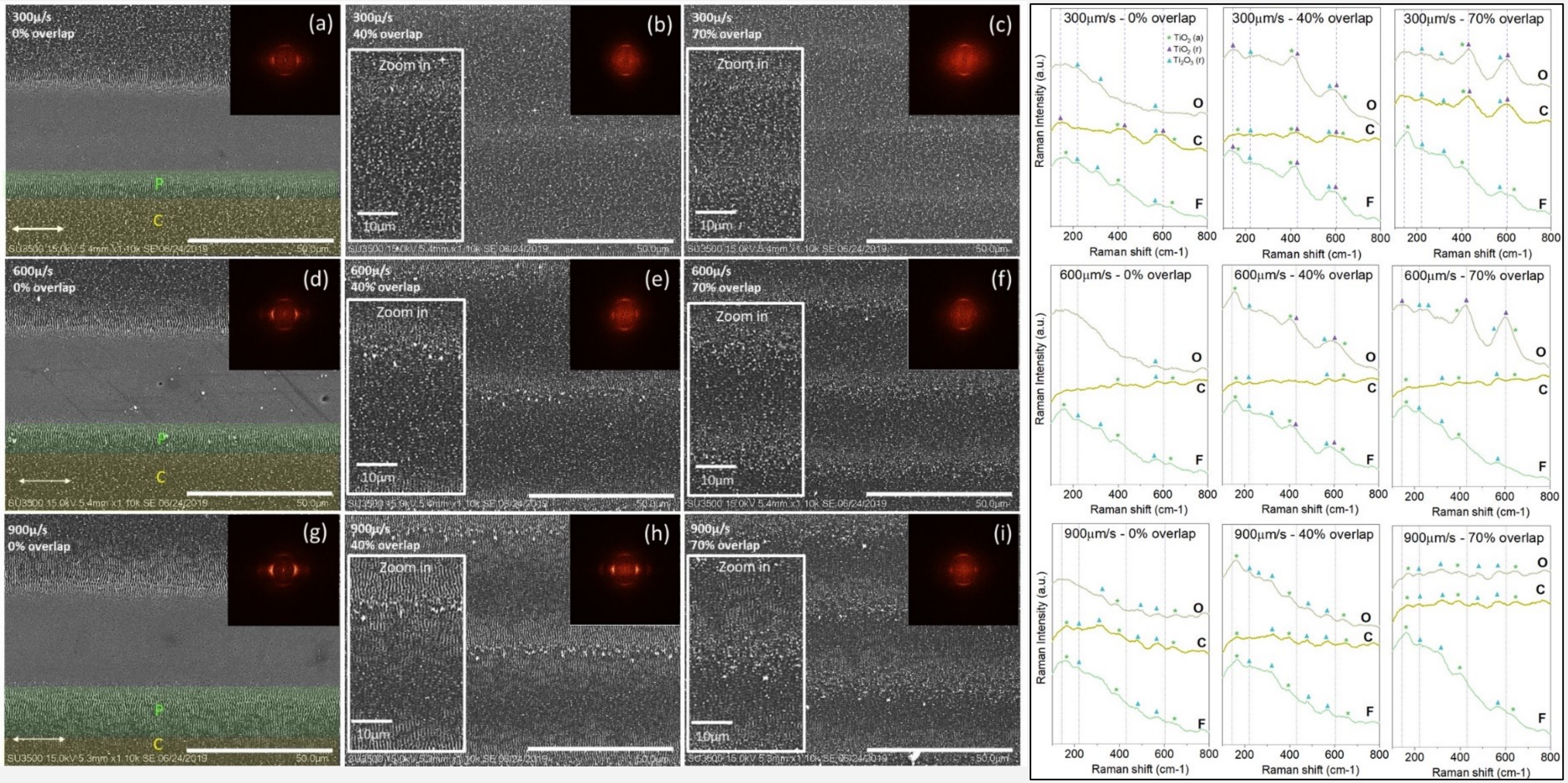




TiO_x LIPSS

fs-large-area fabrication of multi-phase titanium oxide LIPSS on thin films

Lamborghini Sotelo , Ricardo Santillan, Paulina Segovia Olvera , Santiago Camacho López



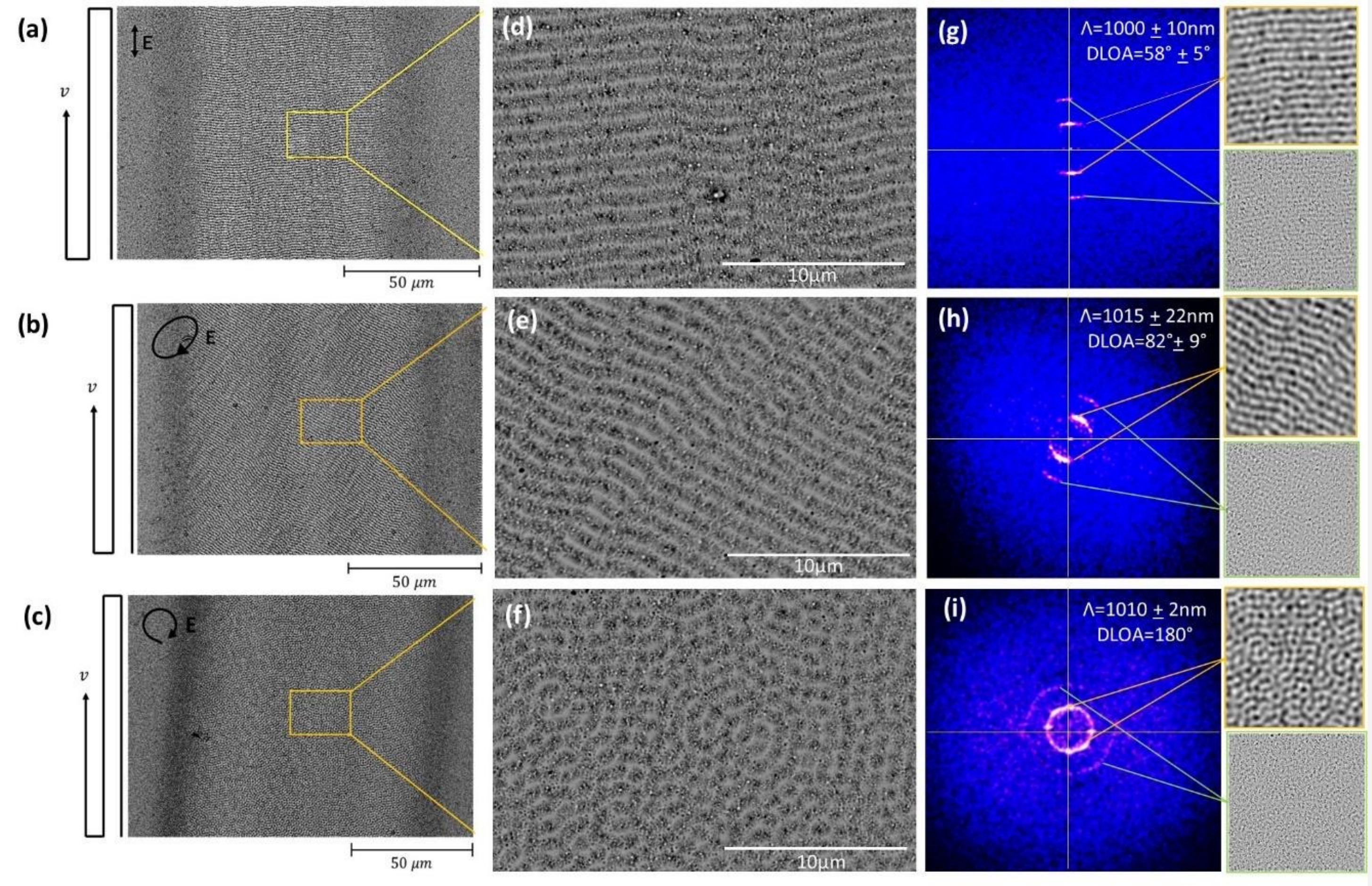
Raman spectra of the Ti film irradiated at a fluence per pulse of 116 mJ/cm^2 for different scanning velocities and overlap rate (0%, 40% and 70%); (a-c) 300 µm/s, (d-f) 600 µm/s, (g-i) 900 µm/s. Raman spectra were measured at different zones, overlap (O), frontier (F) and center (C).

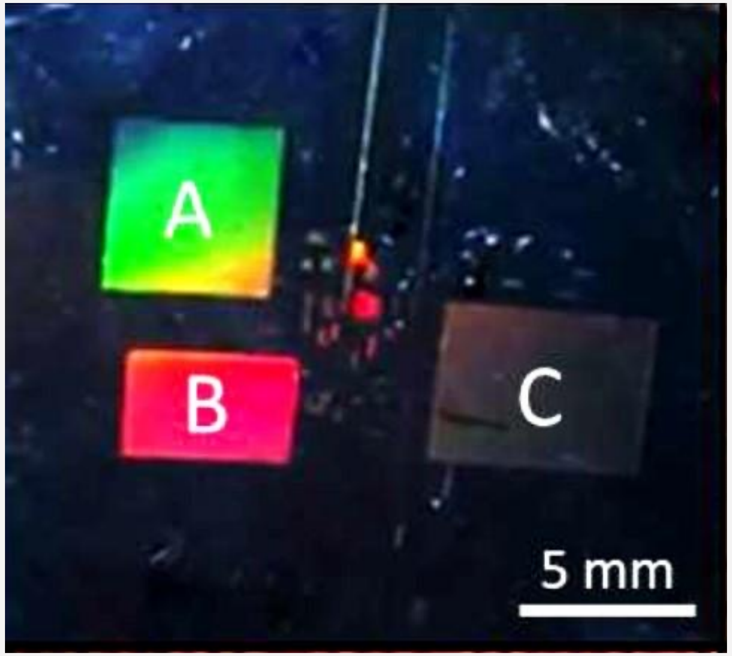
SERS substrates/ structural colors

ULTRASHORT PULSE LASERS
AND PROCESSING OF MATERIALS

Design and fabrication of Bi nanostructured surfaces via LIPSS formation through Surface Plasmons

Abigail Fraijo, Paulina Segovia Olvera, Santiago Camacho López





Picture of the structured colors generated by LIPSS fabricated with linear (A), elliptical (B) and circular (C) polarized radiation

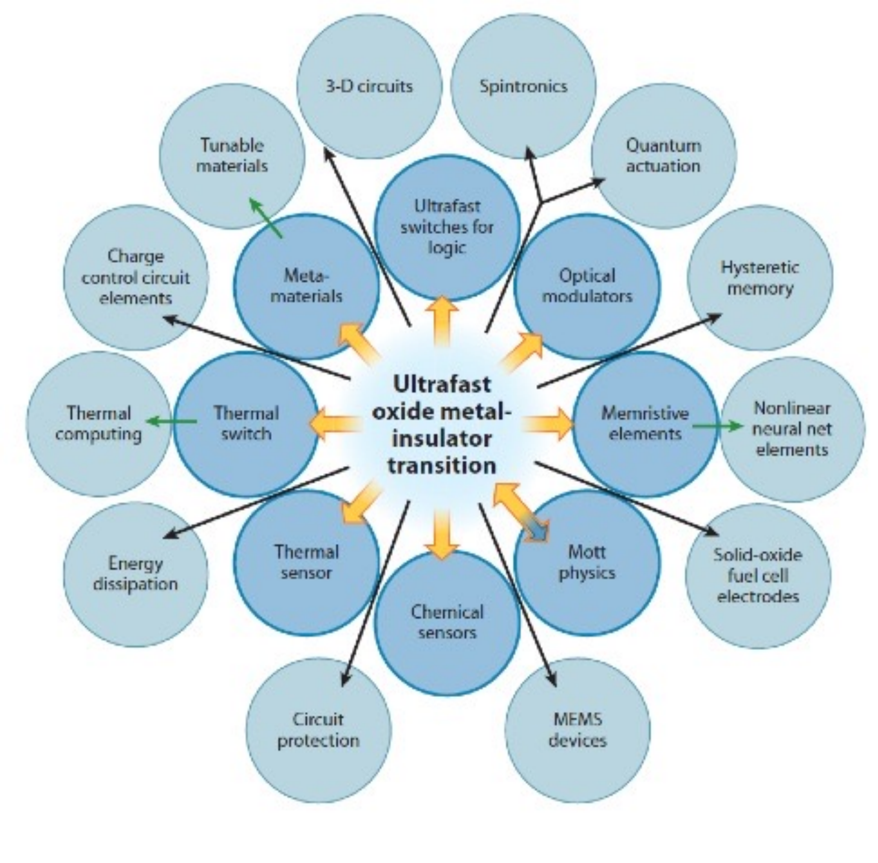
LIPSS on bismuth thin films have applications in fieds like surface coloring, color coding, polarization sensitive displays, surface texturing, diffraction gratings for miniaturized spectroscopy devices, plasmonics for an spectral range from far IR to UV.

Smart materials (VO_2)

Study of fs-lipss formation on V

Noel Ramos, Paulina Segovia Olvera, Santiago Camacho López

Vanadium oxides are chromogenic materials and can change their optical properties due to some external stimuli in the form of photon radiation (photochromic), change in temperature (thermochromic), and voltage pulse (electrochromic)

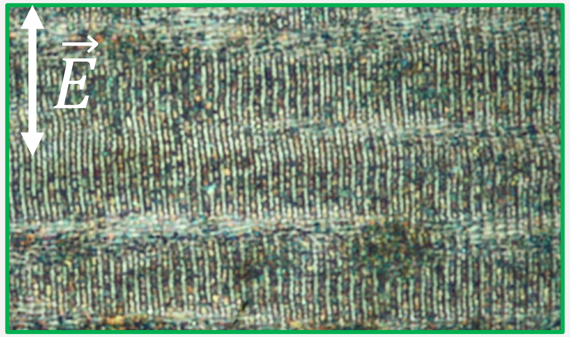


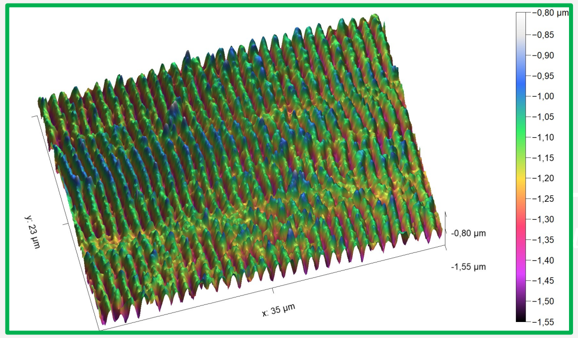
from Yang *et al.*, Annu. Rev. Mater. Res. (2011)

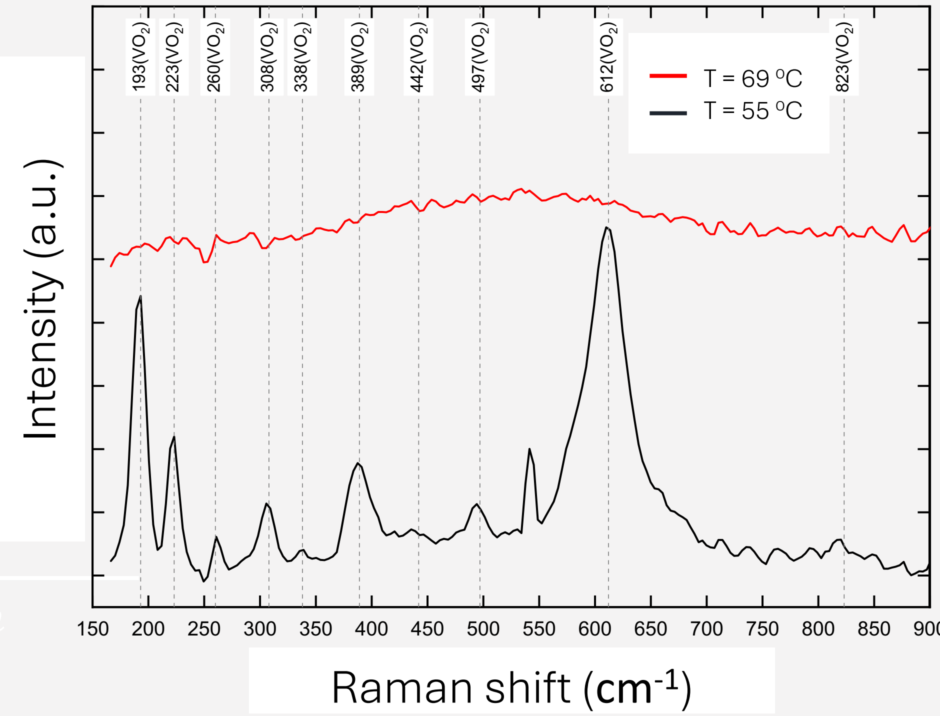
$$F_p = 18.5\ mJ/cm^2$$

Vs= 3. 3μm SLIPSS VO2 ($\Lambda_{\parallel}$=1133 nm)

Depth= 320 nm







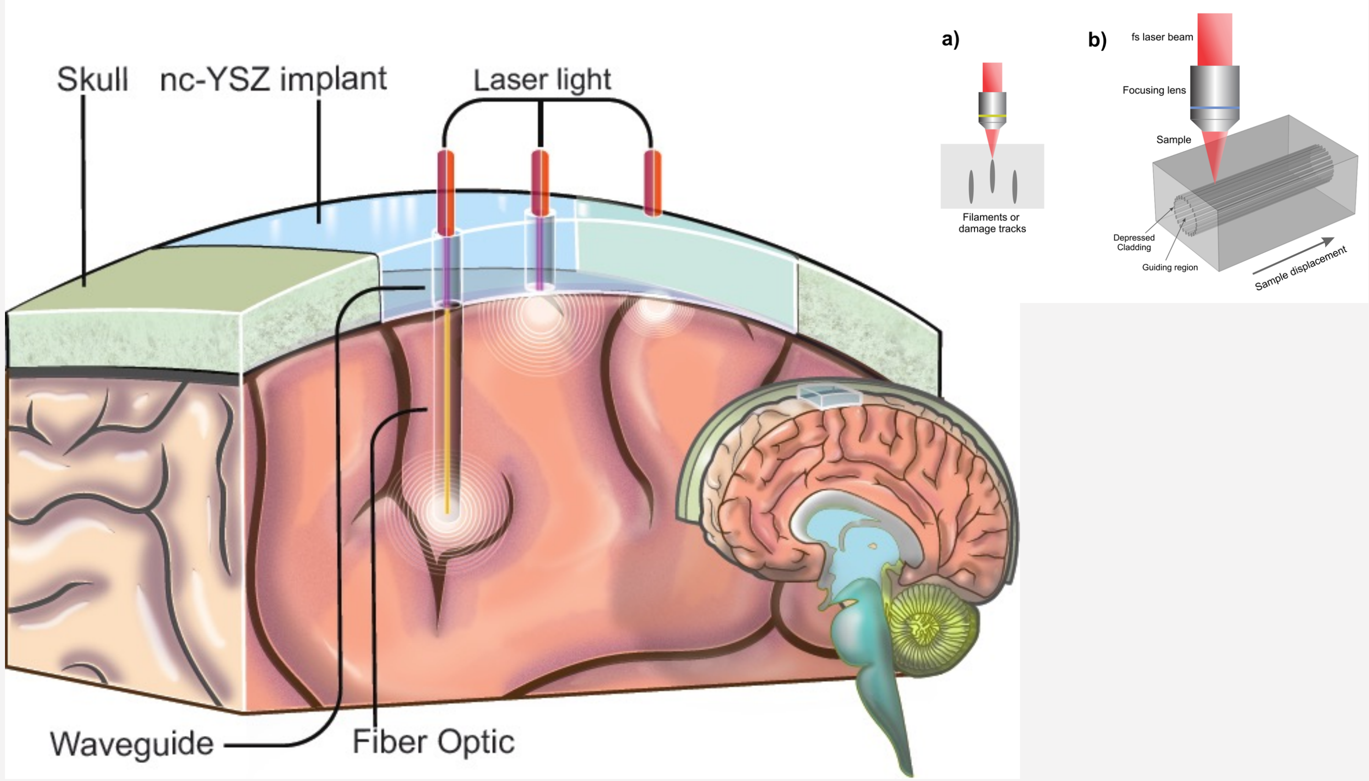
Antibacterial surfaces, cell viability, adhesion and proliferation

ULTRASHORT PULSE LASERS
AND PROCESSING OF MATERIALS

Departamento de Bionanotecnología
Centro de Nanociencias y Nanotecnología

Laser texturing of 8YSZ for skull implants

Luis Fernando Dávila González, Paulina Segovia Olvera, Ana Guadalupe Rodríguez Hernández, Santiago Camacho López



"Circular depressed cladding waveguides in mechanically robust, biocompatible nc-YSZ transparent ceramics by fs laser pulses" C. Guerra-Olvera, G. R. Castillo, E. H. Penilla, G. Uahengo, J. E. Garay, and S. Camacho-Lopez. *Journal of Lightwave Technology* **37**, 3119-3126 (2019).

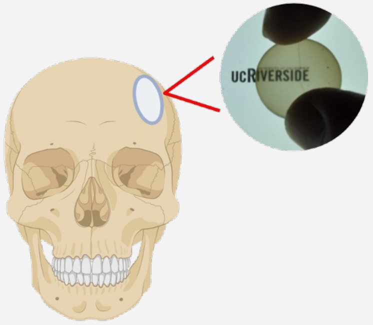
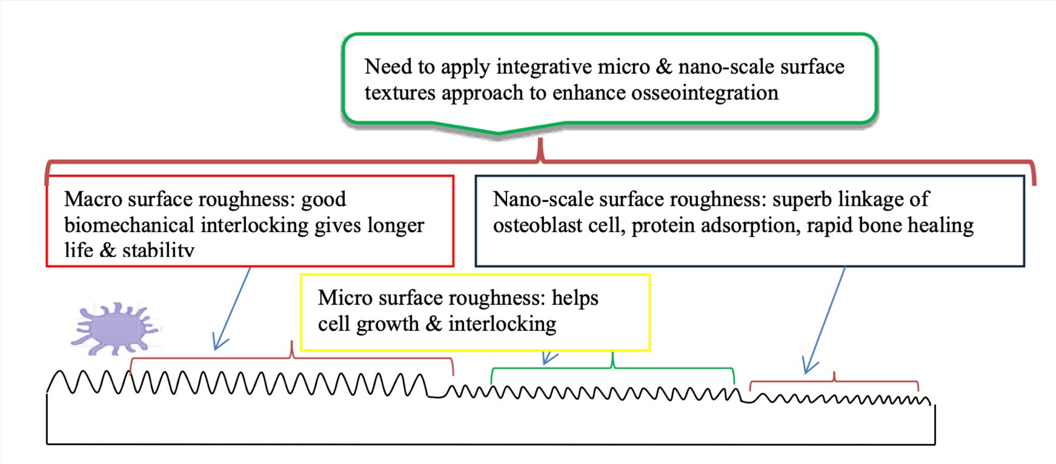


Illustration of implant with 8YSZ sample.. (UC, Riverside, 2010)

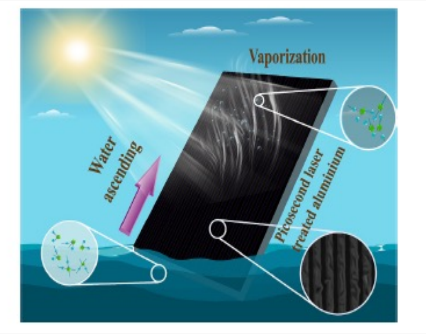


Influence of topography on the osteointegration process.(Sirdeshmukh & Dongre, 2021)

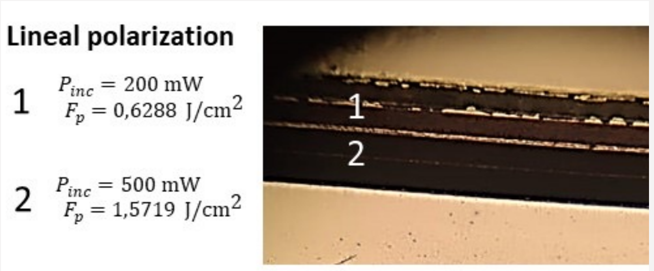
Renewable energy and water

fs - laser blackening of aluminum alloy for water desalination

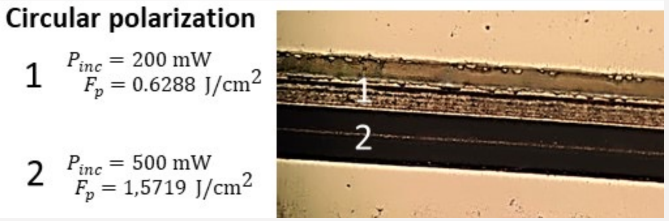
Leydy Velásco , Paulina Segovia Olvera, Francisco Carranza, Santiago Camacho López.



Super-blackening and hydrophilic surface

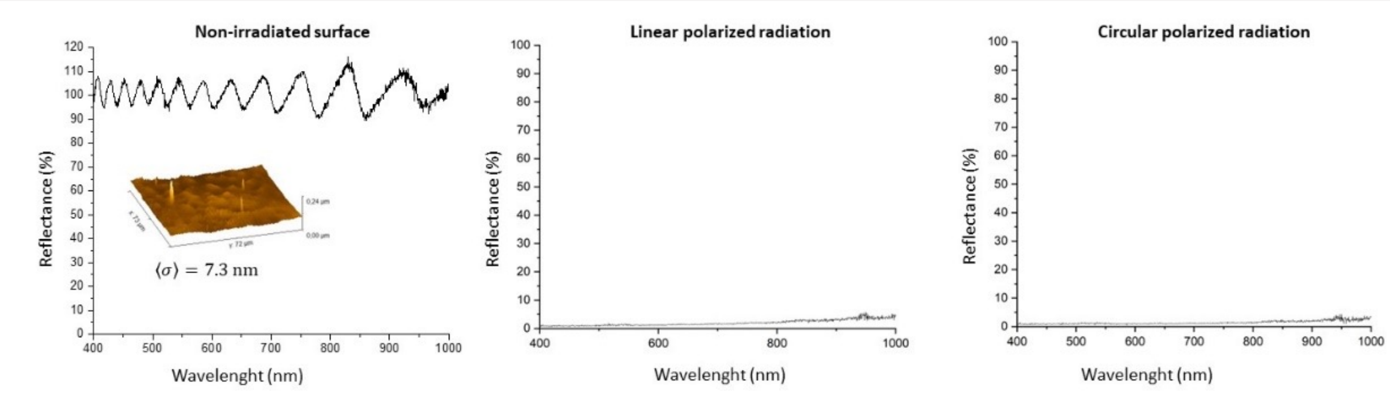


Light trapping microstructure and nanostructure is generated to absorb light from UV, visible to long-wave infrared spectral region.

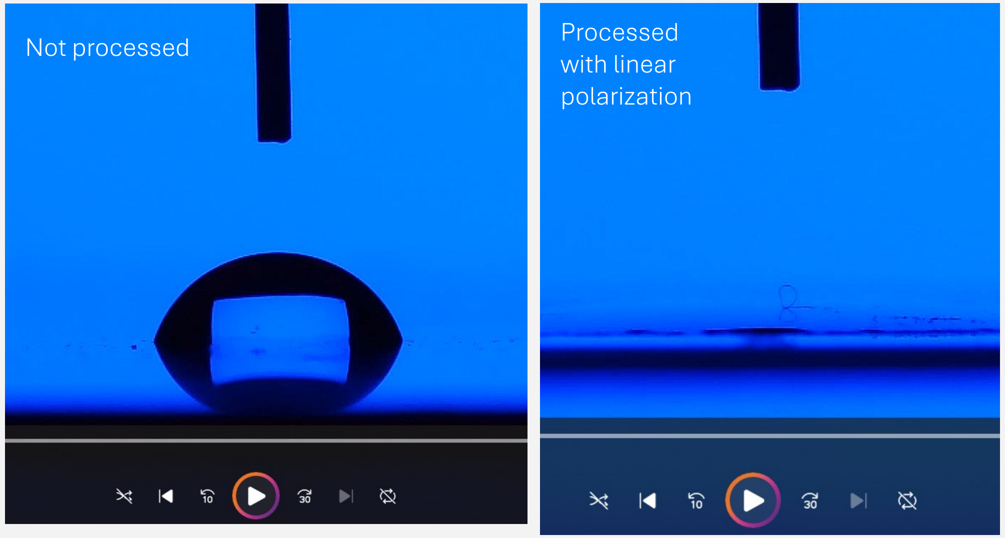


Abosrption of light due to mulitple reflections, excitation of suface plasmons polaritons and excitation of loclized Surface plasmons.

Optical Micrographs of modified aluminum surface showing different colors: brown, golden, and black.



Reflectance for Al alloy before processing and after blackening with linear and circular polarized radiation.



Modifying wettability on Al Surface.

LASER INDUCED CAVITATION BUBBLES:
STUDIES AND APPLICATIONS IN BIO AND ENVIROMENT

Cavitation occurs when $P_{Fluid} << P_{vapor}$

Boiling water

- Fluid Pressure << Vapor Pressure
  (Constant) ↑

Low pressure regions

- Fluid Pressure << Vapor Pressure
  ↓ (Constant)

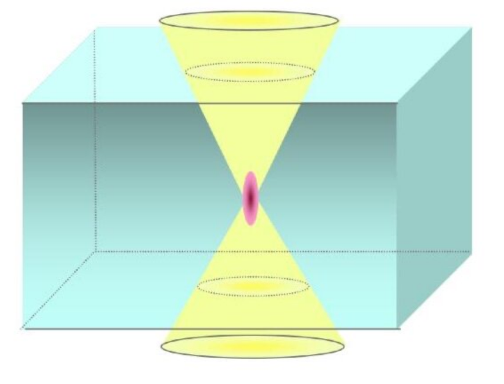
Laser induced

Photoionization

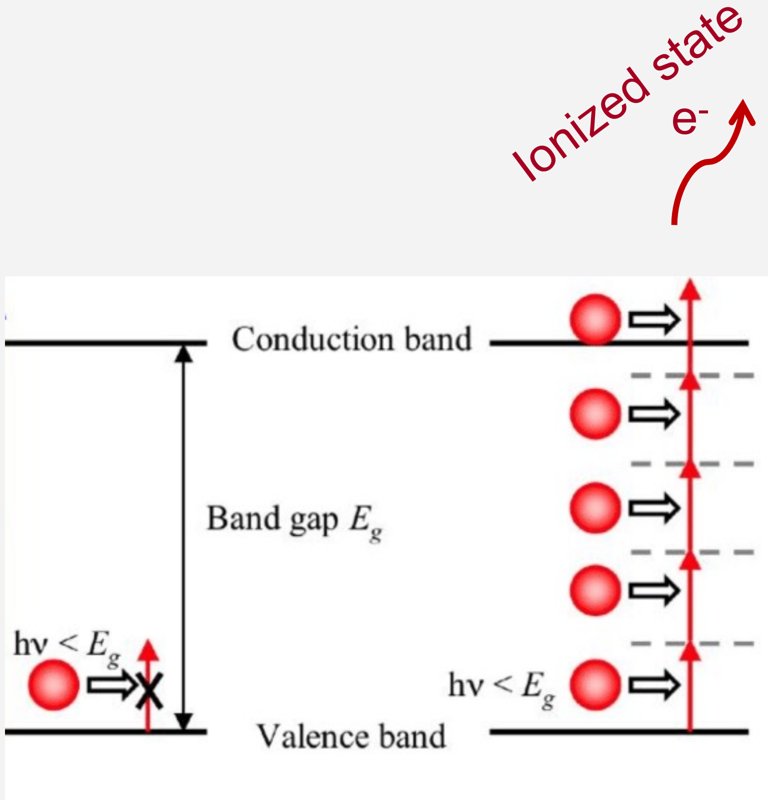
- Fluid Pressure << Vapor Pressure
  (Constant) ↑

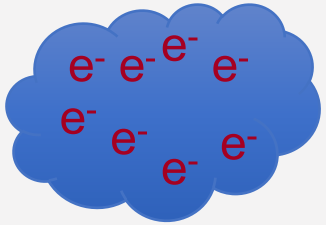
LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Photoionization (nanoseconds and shorter pulses)

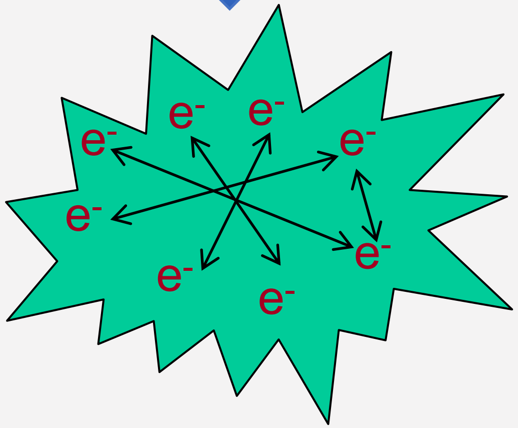


Focused laser beam leads to a high irradiated volume

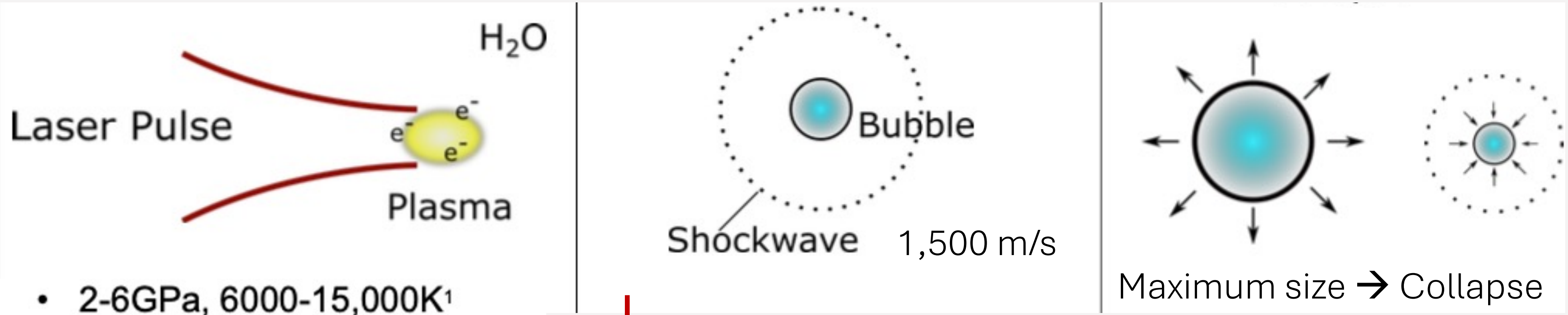




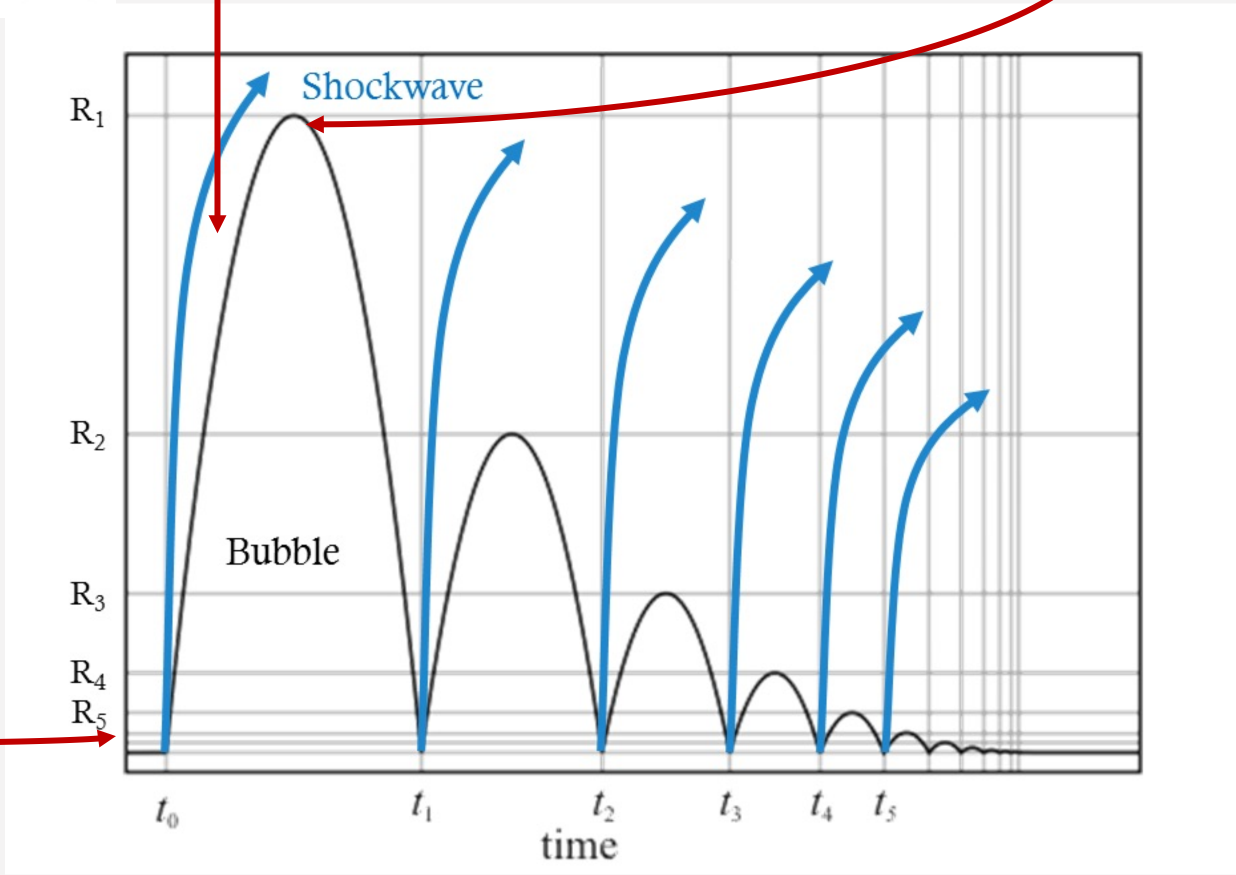
Critic density
N>10²¹ cm−3



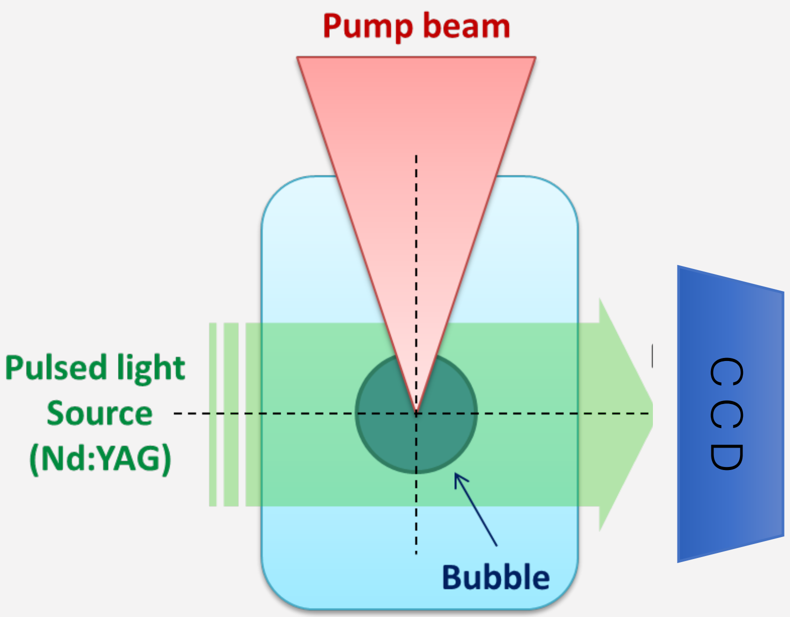
Microexplosión

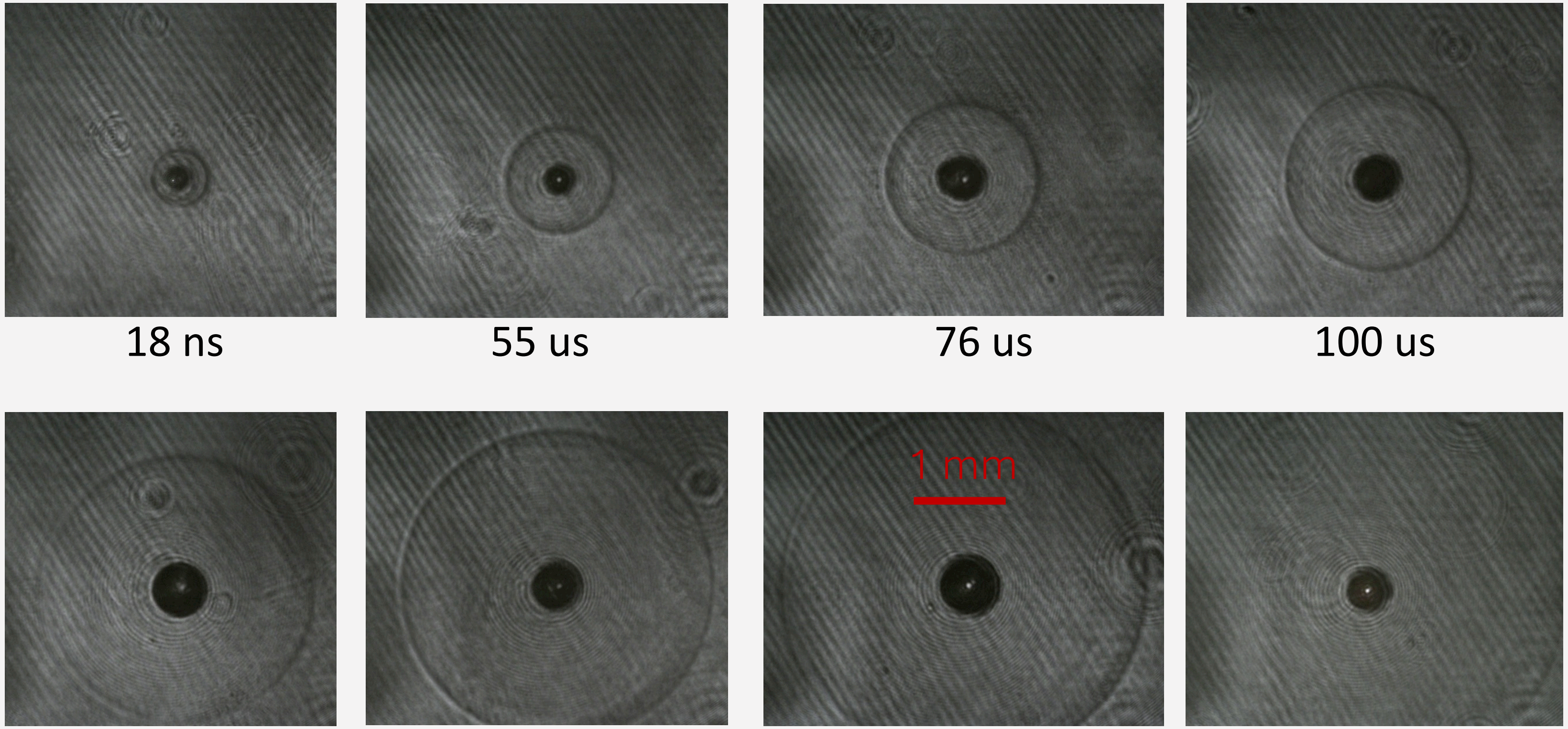


- 2-6GPa, 6000-15,000K[1]
- ~10ns duration, ~100µm size[2]



Laser shadowgraphy [750 μJ]

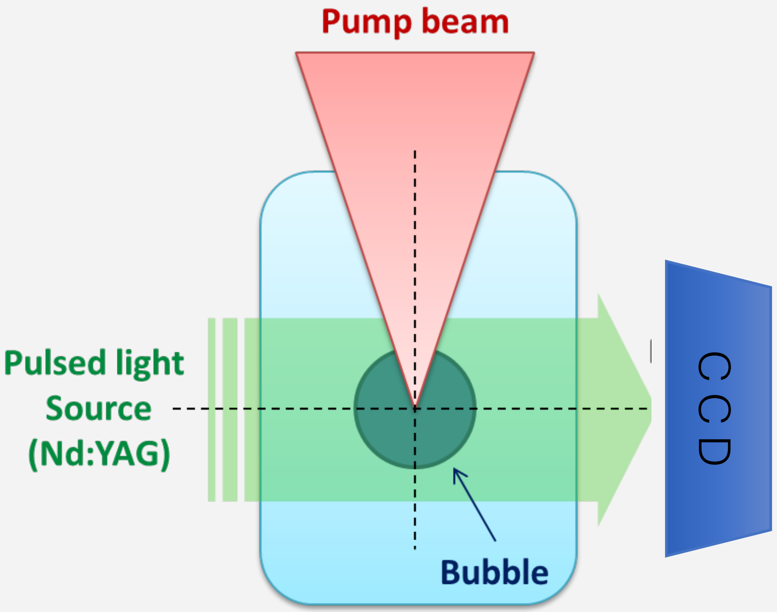


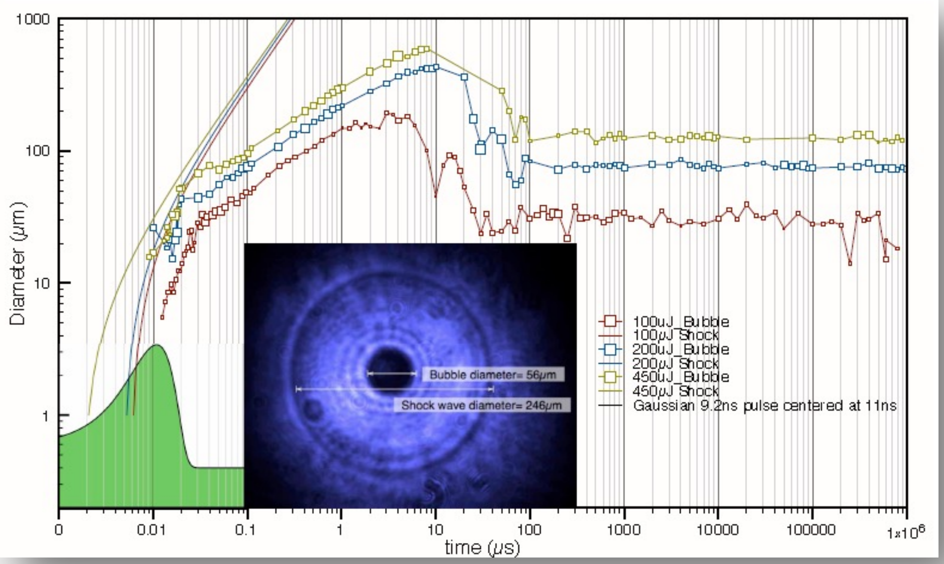


18 ns | 55 us | 76 us | 100 us
163 us | 188 us | 229 us | 272 us

LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Cavitation bubble dynamics reconstruction by Laser Shadowgraphy.





LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Tesis doctoral de Rodger Evans, dirigida por el Dr. Santiago Camacho L.
Fenómenos físicos en el microprocesado de materiales con láser. 2009. FA-CICESE

Laser induced cavitation bubble: studies from 2012 to 2023

LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

applied sciences

MDPI

2020

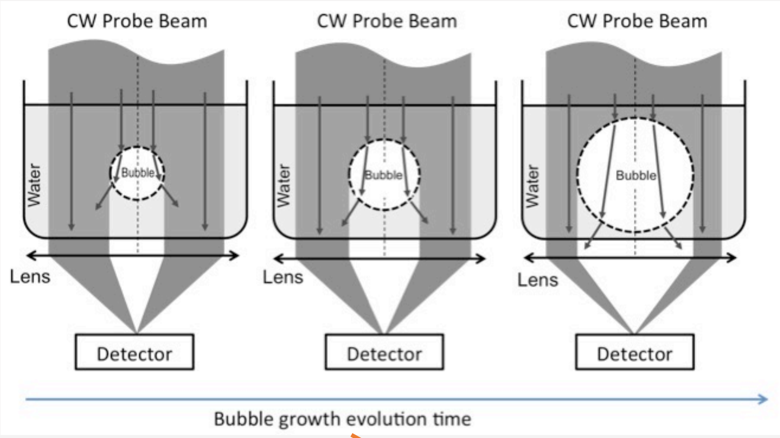
Article

Intraocular Pressure Study in Ex Vivo Pig Eyes by the Laser-Induced Cavitation Technique: Toward a Non-Contact Intraocular Pressure Sensor

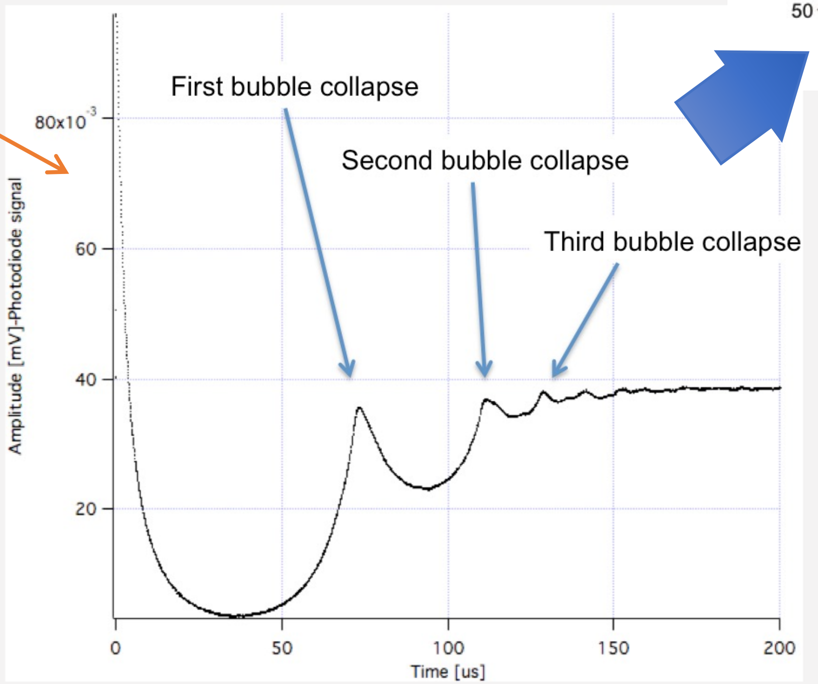
Santiago Camacho-Lopez [1], Carlos Andrés Zuñiga-Romero [1], Luis Felipe Devia-Cruz [2,*], Carolina Alvarez-Delgado [3], Marcos Antonio Plata-Sanchez [1] and Leopoldo Martinez-Manuel [1]

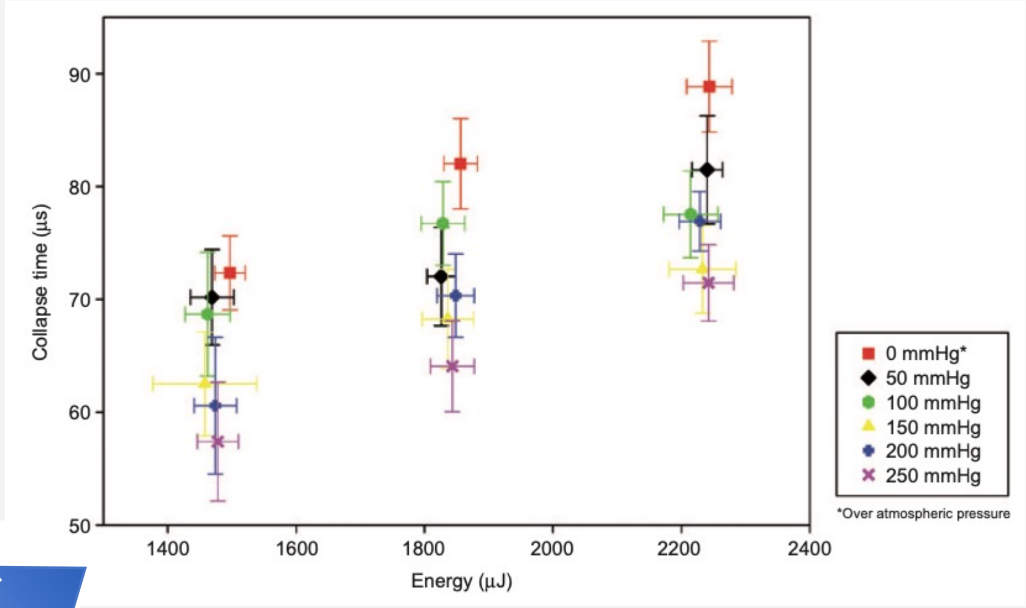
LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Results

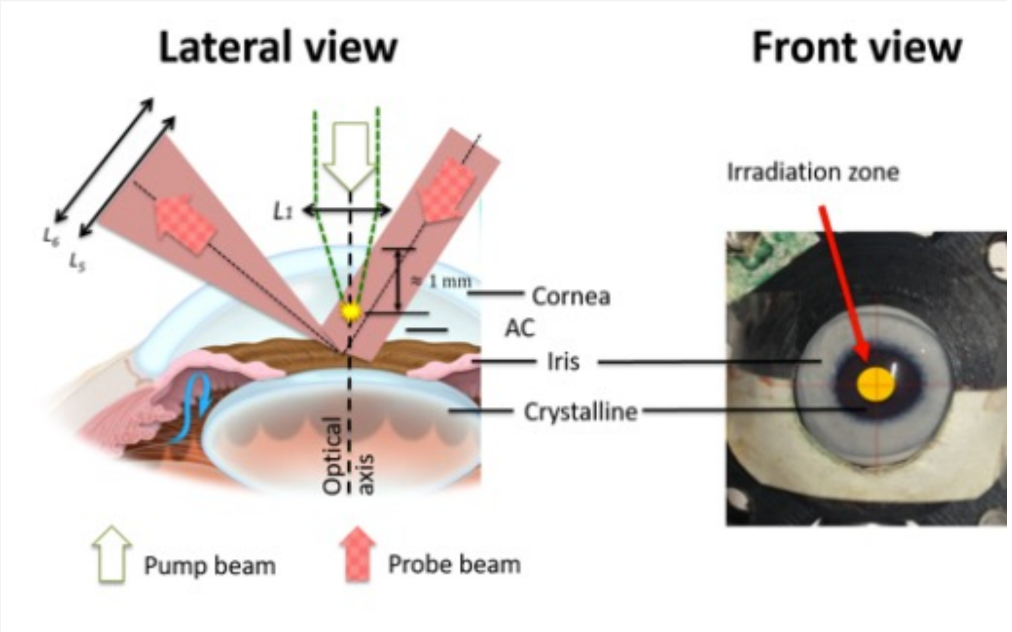


Intensidad medida

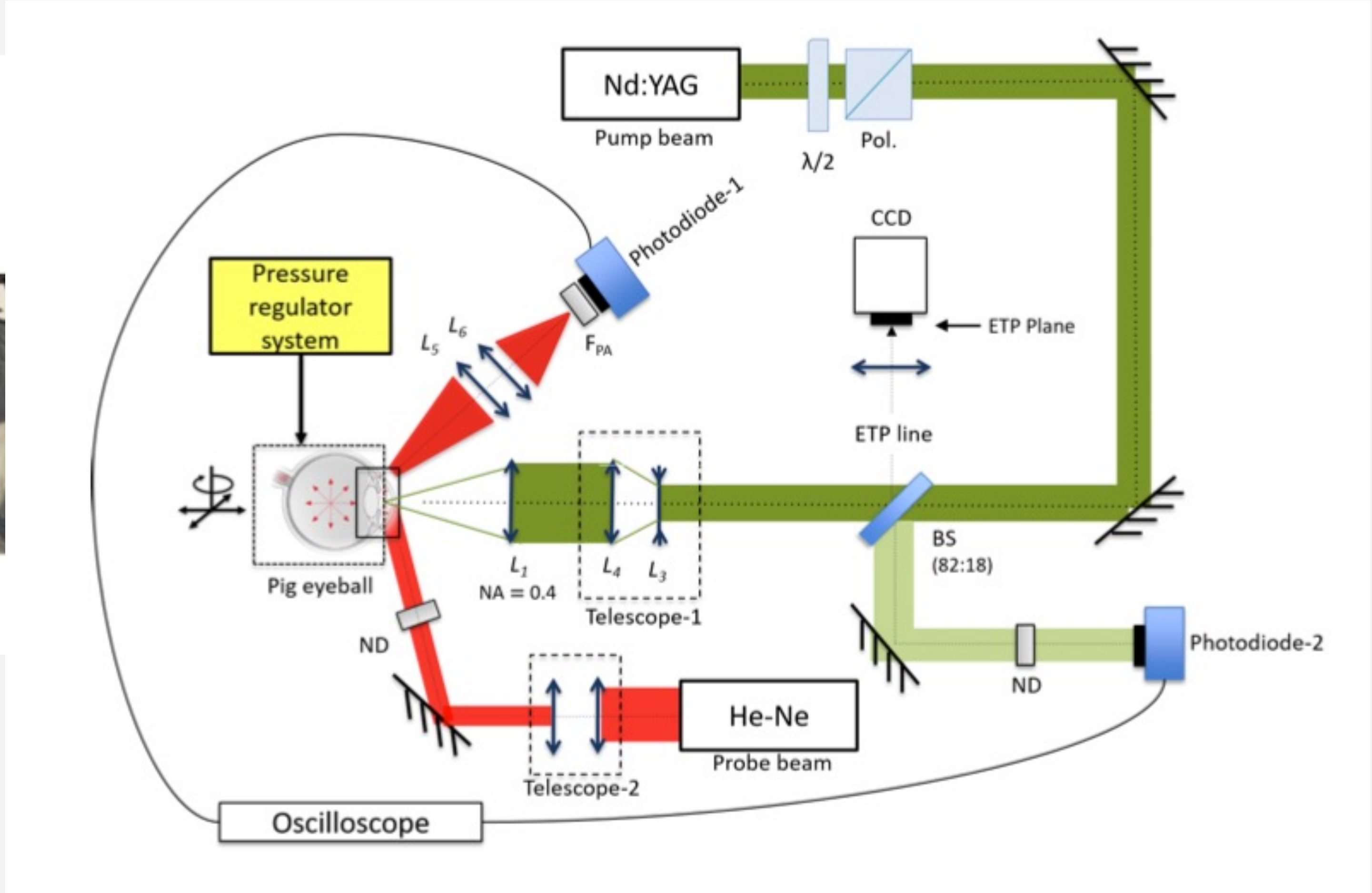




Results



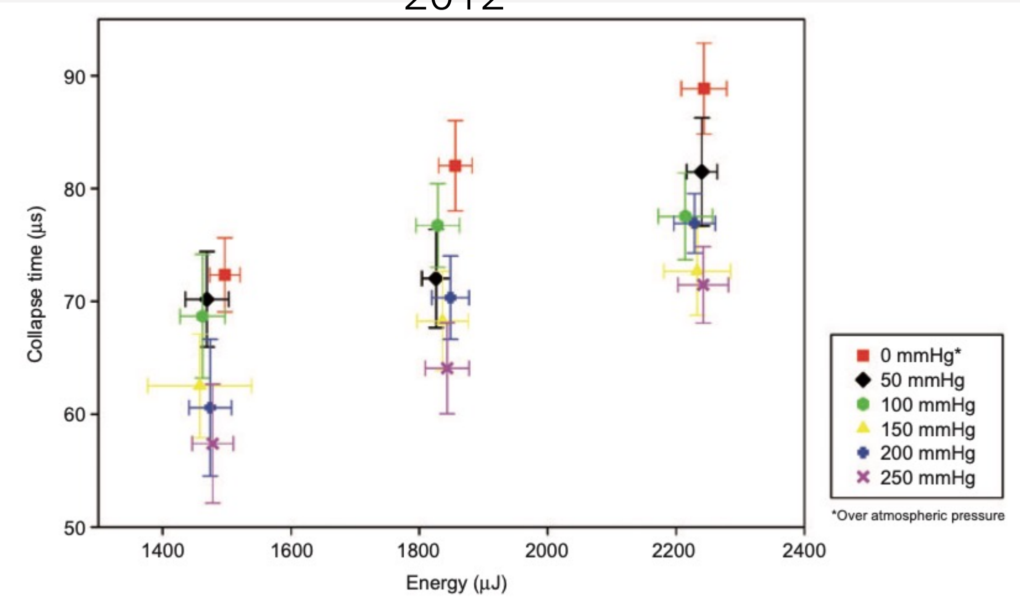
Lateral view
Front view
L1
L6
L5
≈ 1 mm
Cornea
AC
Iris
Crystalline
Optical axis
Irradiation zone
Pump beam
Probe beam



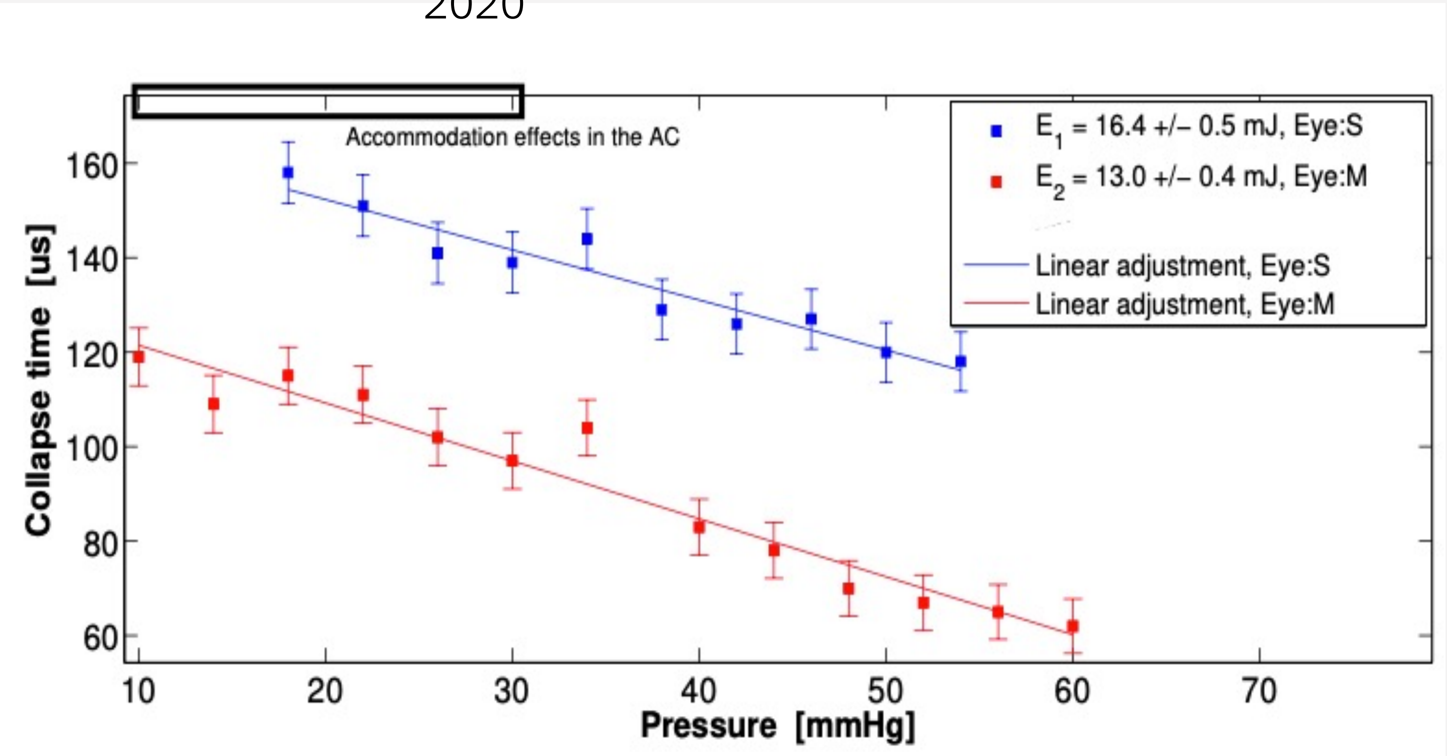
Nd:YAG
Pump beam
λ/2
Pol.
Photodiode-1
F_{PA}
CCD
ETP Plane
ETP line
Pressure regulator system
L_6
L_5
Pig eyeball
L_1
NA = 0.4
L_4
L_3
Telescope-1
BS
(82:18)
ND
Photodiode-2
ND
He-Ne
Probe beam
Telescope-2
Oscilloscope

Results

2012



2020



LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Atomization and Sprays, 23 (6): 505–515 (2013)

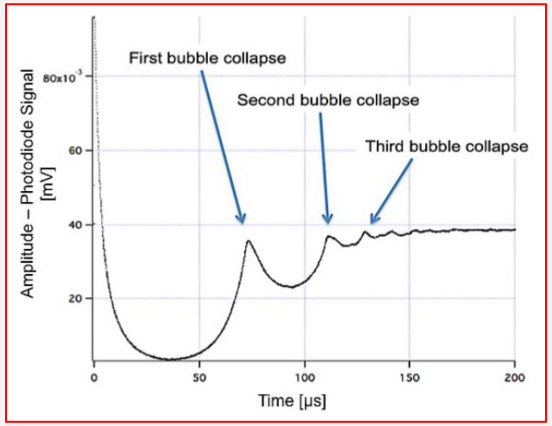
HIGH RESOLUTION OPTICAL EXPERIMENTAL TECHNIQUE FOR COMPUTING PULSED LASER-INDUCED CAVITATION BUBBLE DYNAMICS IN A SINGLE SHOT

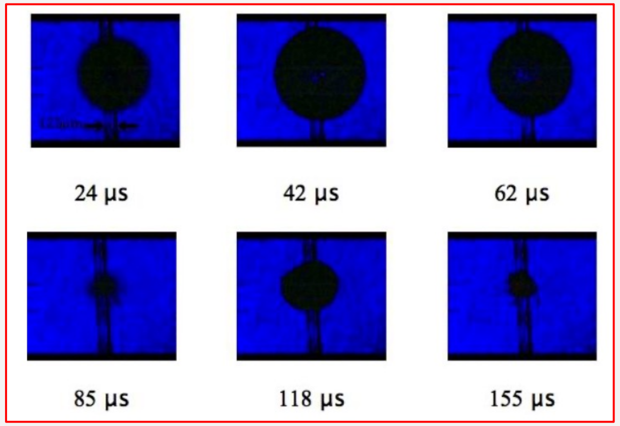
Luis Felipe Devia-Cruz,[1,] Francisco G. Pérez-Gutiérrez,[2] Daniel García-Casillas,[3] Guillermo Aguilar,[3] Santiago Camacho-López,[1] & Darren Banks[3]*

LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

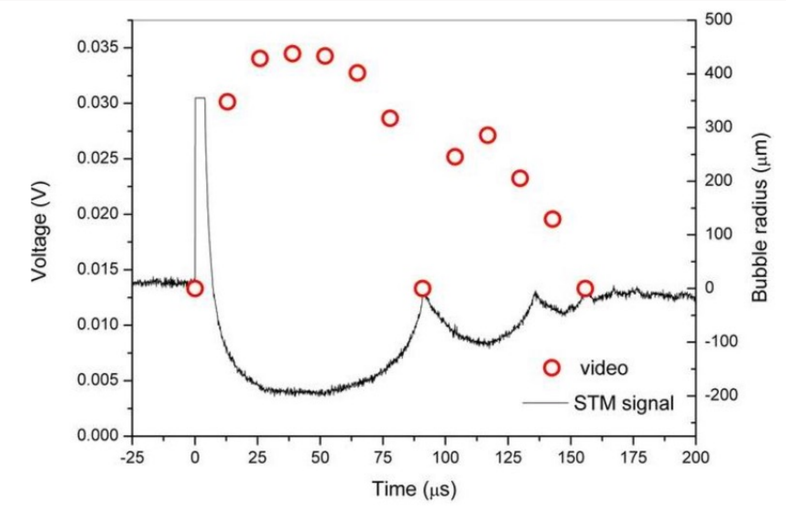
Results

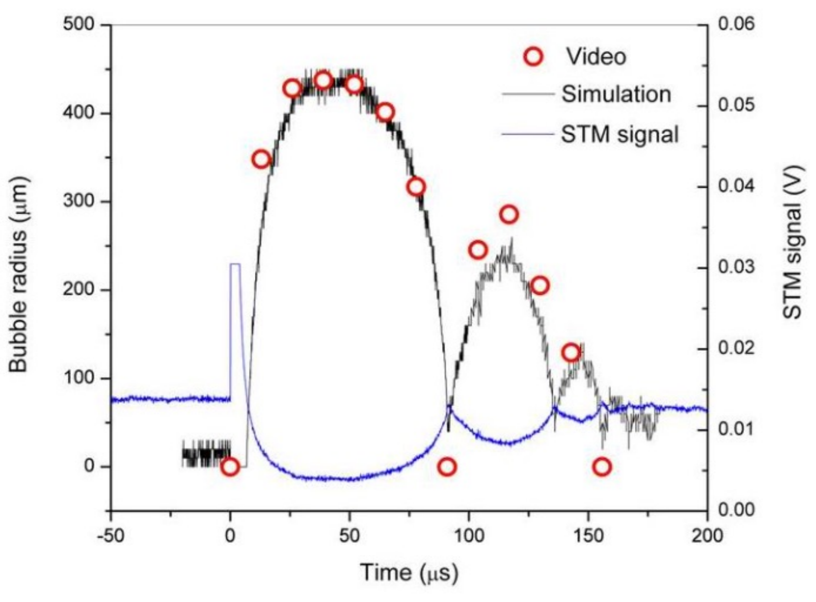
$$STMt = \frac{\int_{-w}^{w} e^{-r^2/2w^2}dr - \int_{-rp}^{rp} e^{-r^2/2w^2}dr}{\int_{-w}^{w} e^{-r^2/2w^2}dr}$$





Video de alta Velocidad





LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

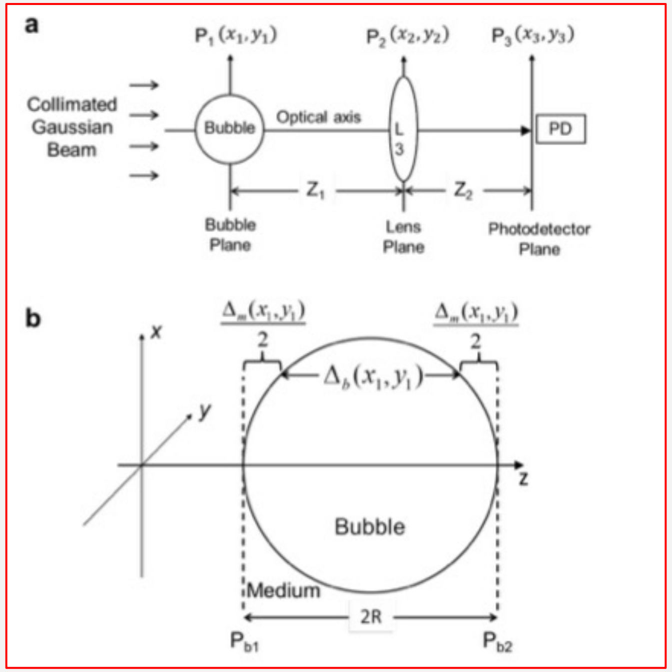
Applied Optics Vol. 54, Issue 35, pp. 10432-10437 (2015) • https://doi.org/10.1364/AO.54.010432

Reconstruction of laser-induced cavitation bubble dynamics based on a Fresnel propagation approach

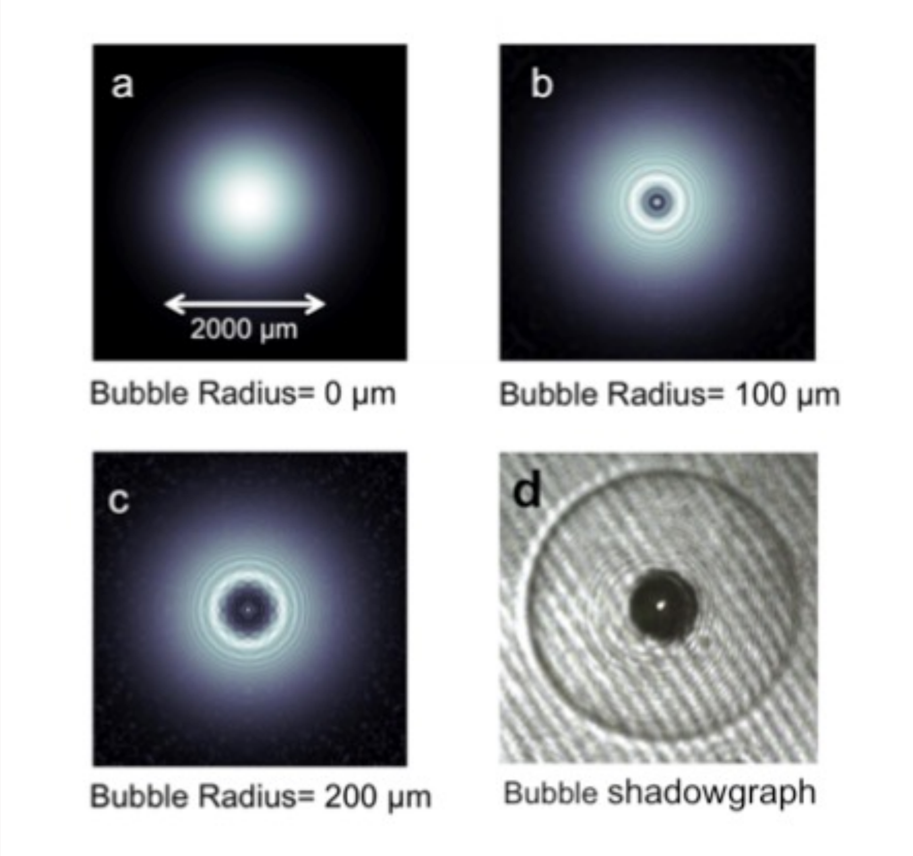
Luis Felipe Devia-Cruz, Santiago Camacho-López, Víctor Ruiz Cortés, Victoria Ramos-Muñiz, Francisco G. Pérez-Gutiérrez, and Guillermo Aguilar

LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

Results



$$E(x_2,y_2)=\frac{e^{ikz_1}}{i\lambda z_1}e^{i\frac{k}{2z_1}\left(x_2^2+y_2^2\right)}\Im\left\{E_b(x_1,y_1)e^{i\frac{k}{2z_1}\left(x_1^2+y_1^2\right)}\right\}\Bigg|_{\substack{f_x=x_2/\lambda z_1\\ f_y=y_2/\lambda z_1}} \tag{10}$$



LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

Microsystem Technologies (2021) 27:801–812
https://doi.org/10.1007/s00542-020-04998-0

TECHNICAL PAPER

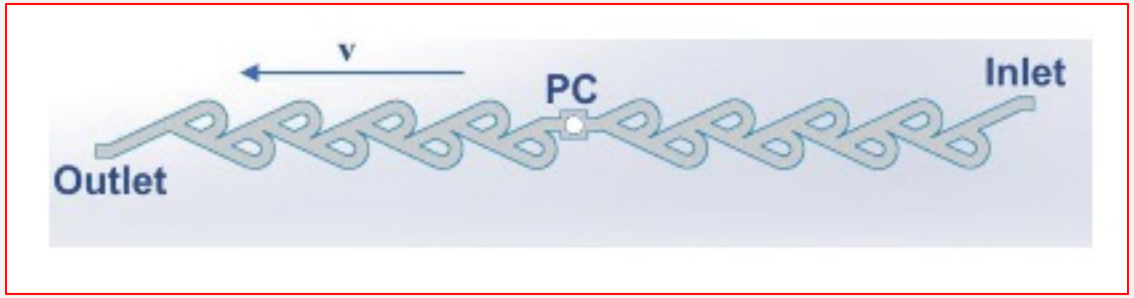
Numerical modeling of a micropump without mobile parts actuated by thermocavitation bubbles

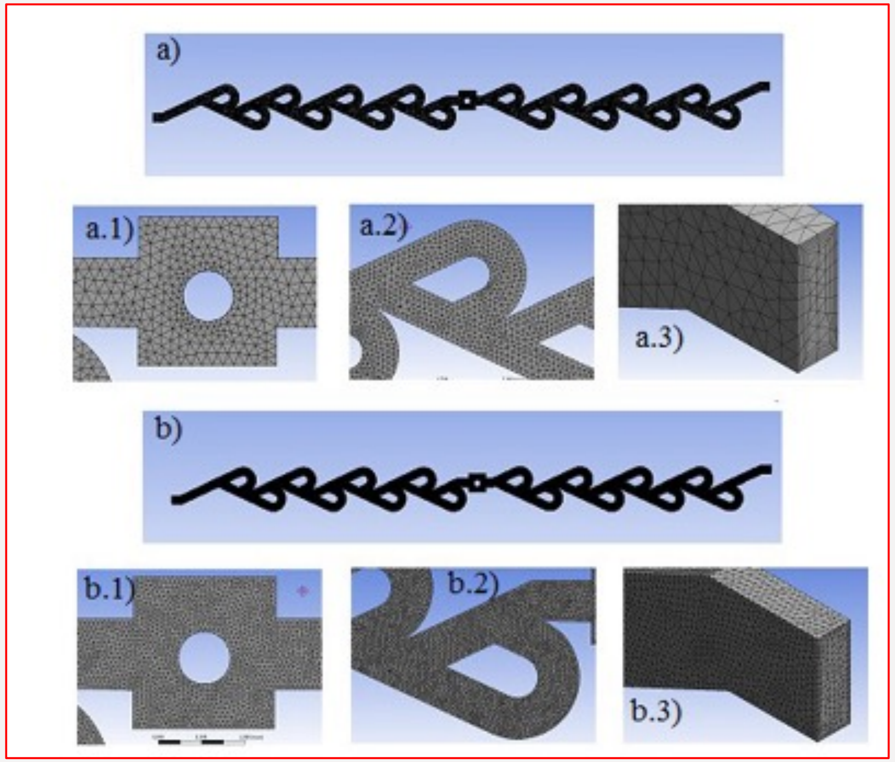
N. G. García-Morales[1] · B. Morales-Cruzado[2] · S. Camacho-López[3] · R. Romero-Méndez[1] · L. F. Devia-Cruz[3] · F. G. Pérez-Gutiérrez[1]

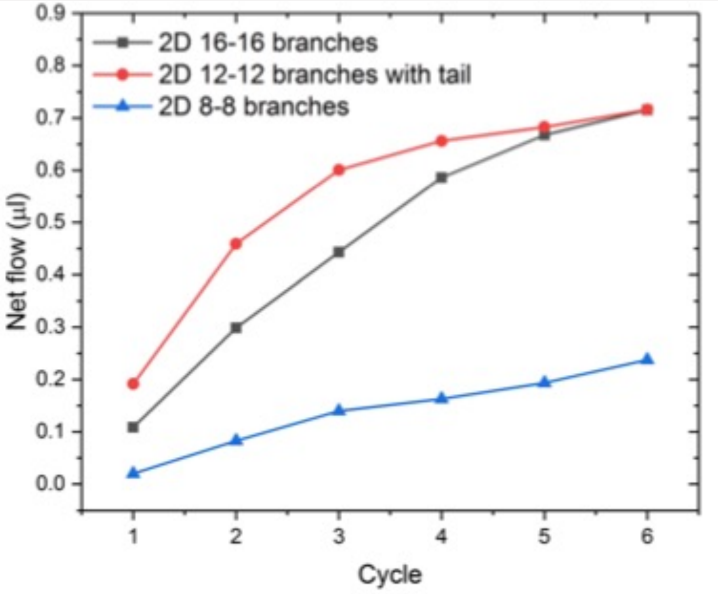
Received: 3 June 2020 / Accepted: 8 August 2020 / Published online: 20 August 2020

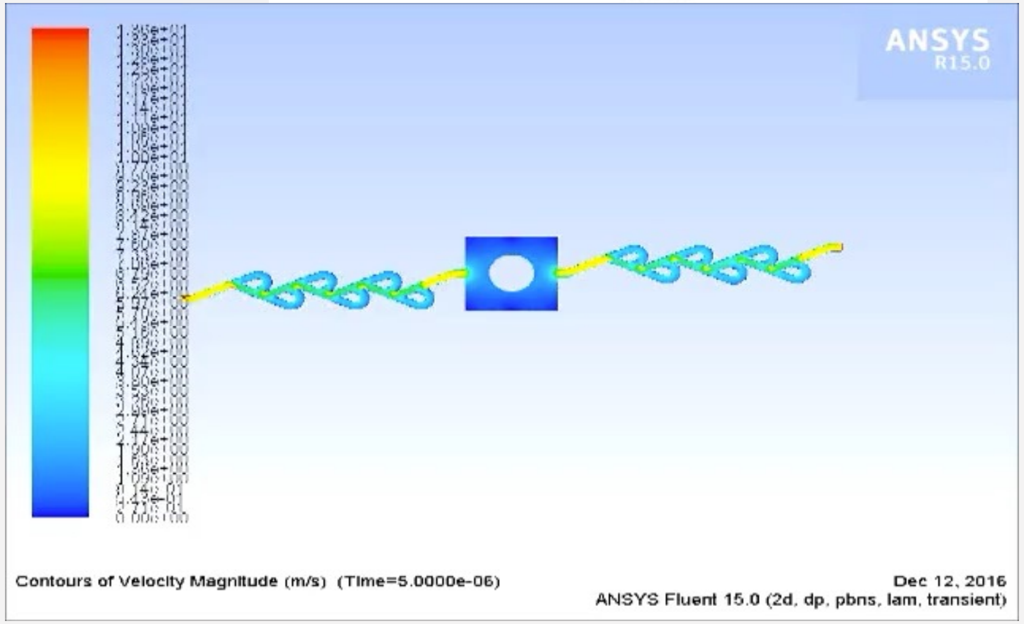
LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

Results









LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

Physics of Fluids

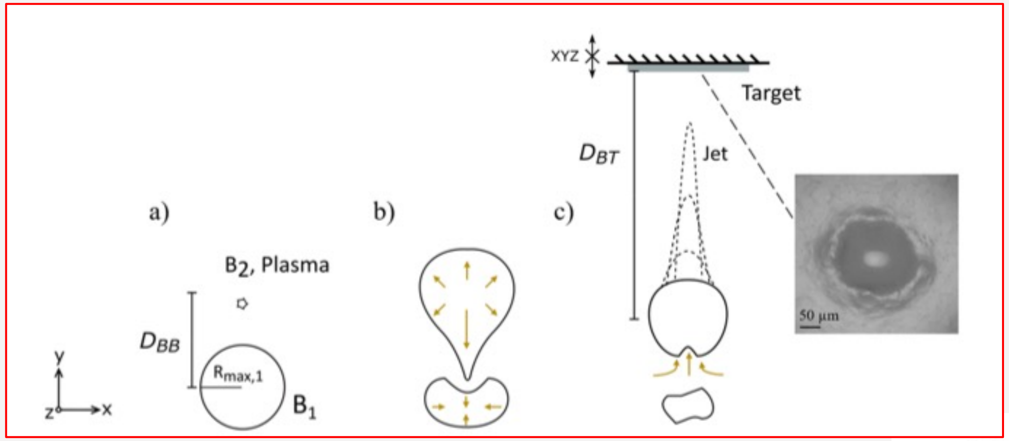
Soft material perforation via double-bubble laser-induced cavitation microjets

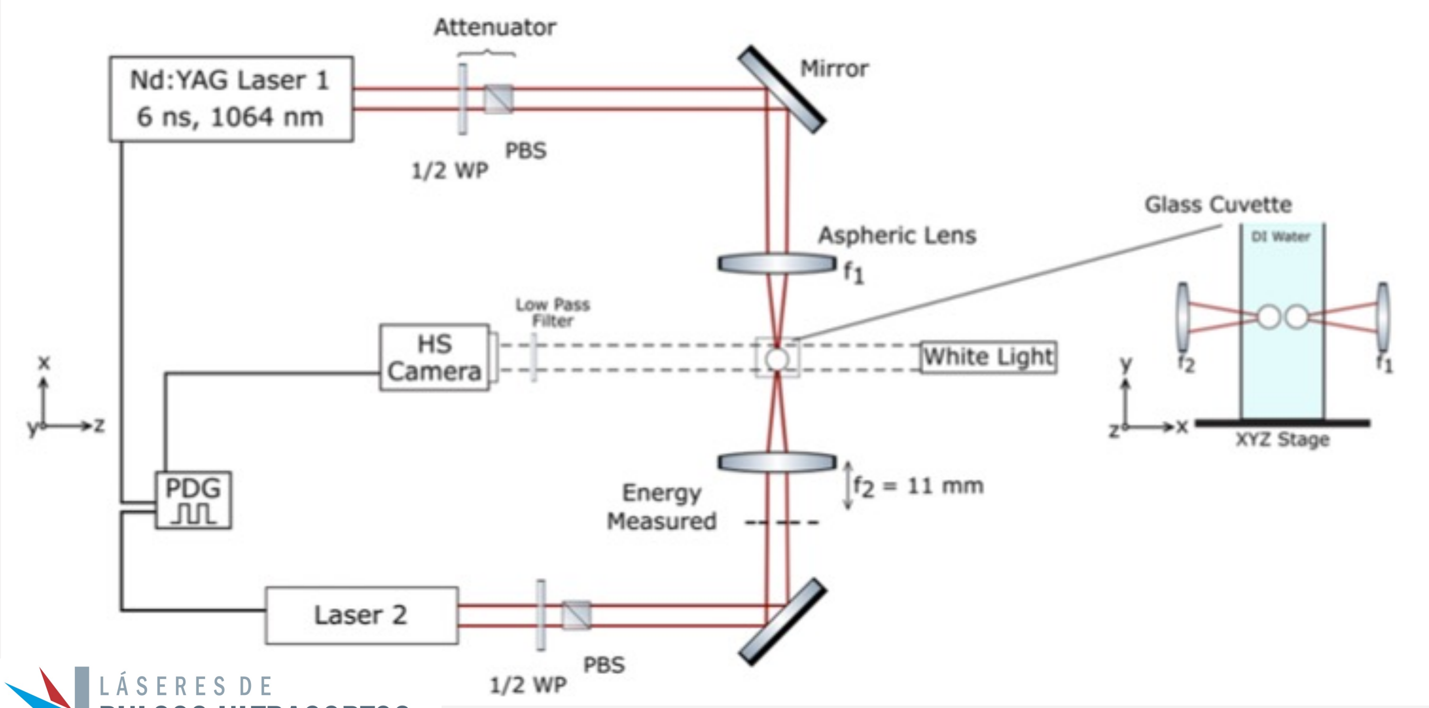
Cite as: Phys. Fluids **32**, 042005 (2020); https://doi.org/10.1063/5.0007164
Submitted: 09 March 2020 . Accepted: 02 April 2020 . Published Online: 22 April 2020

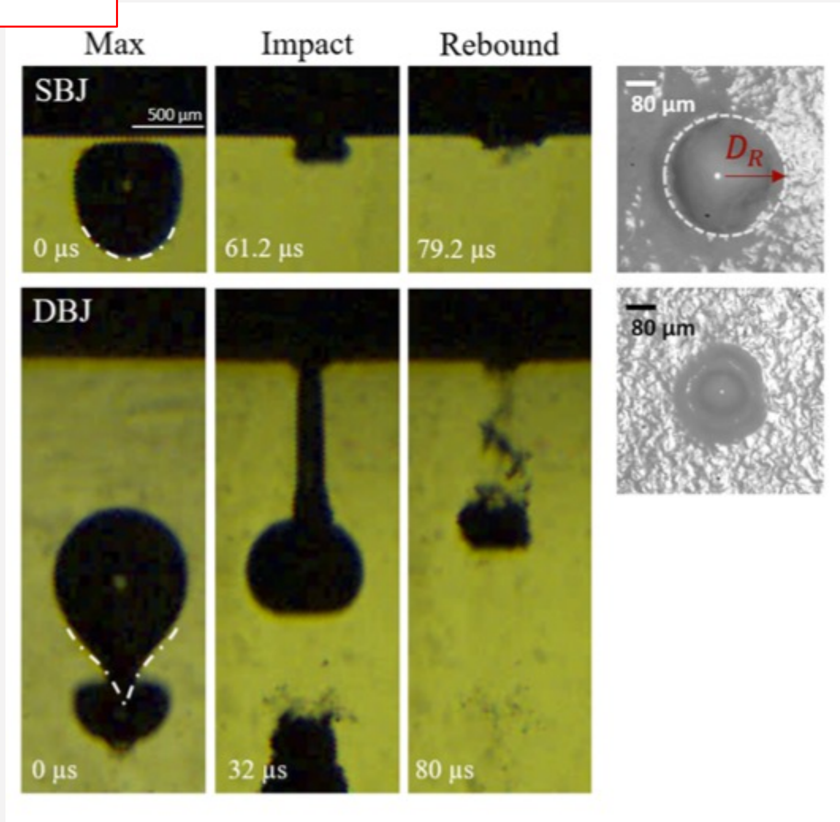
V. Robles, E. Gutierrez-Herrera, L. F. Devia-Cruz, D. Banks, S. Camacho-Lopez, and G. Aguilar

LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

Results

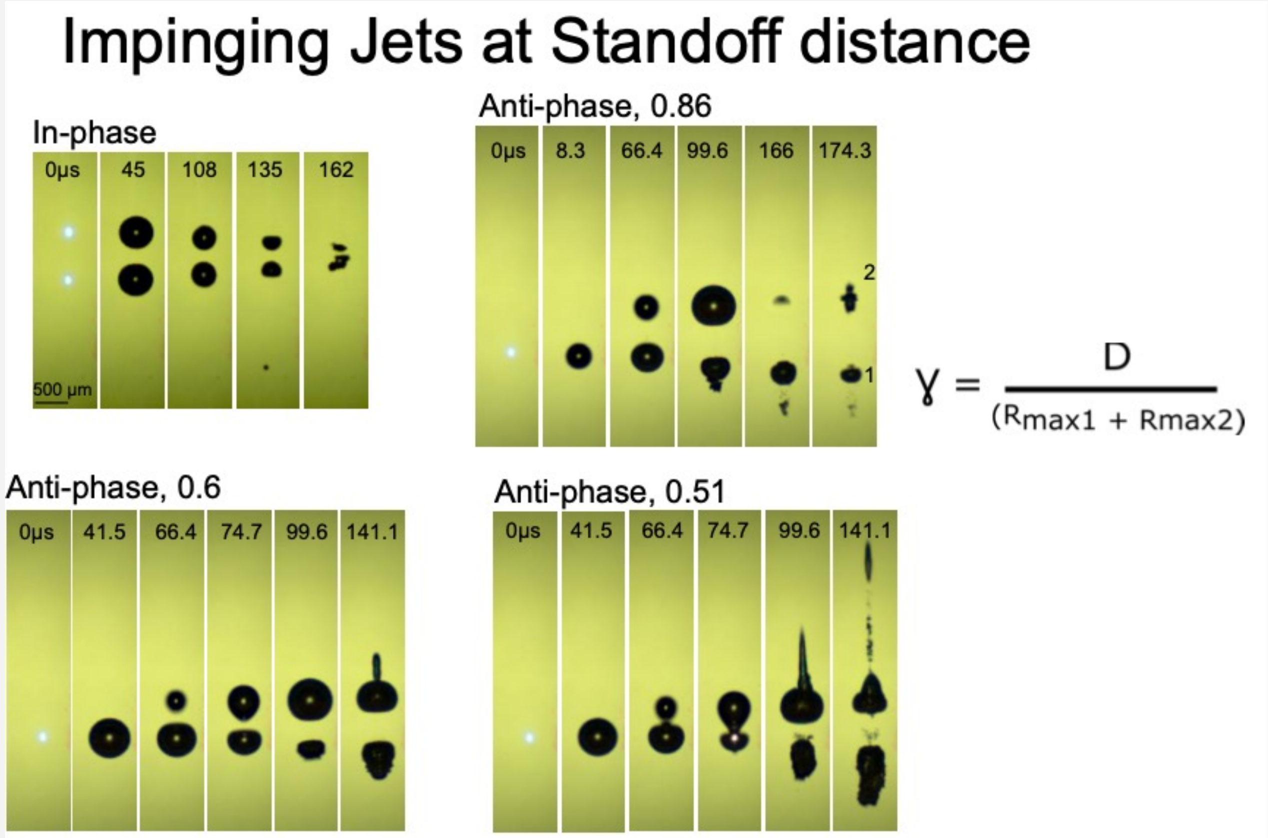


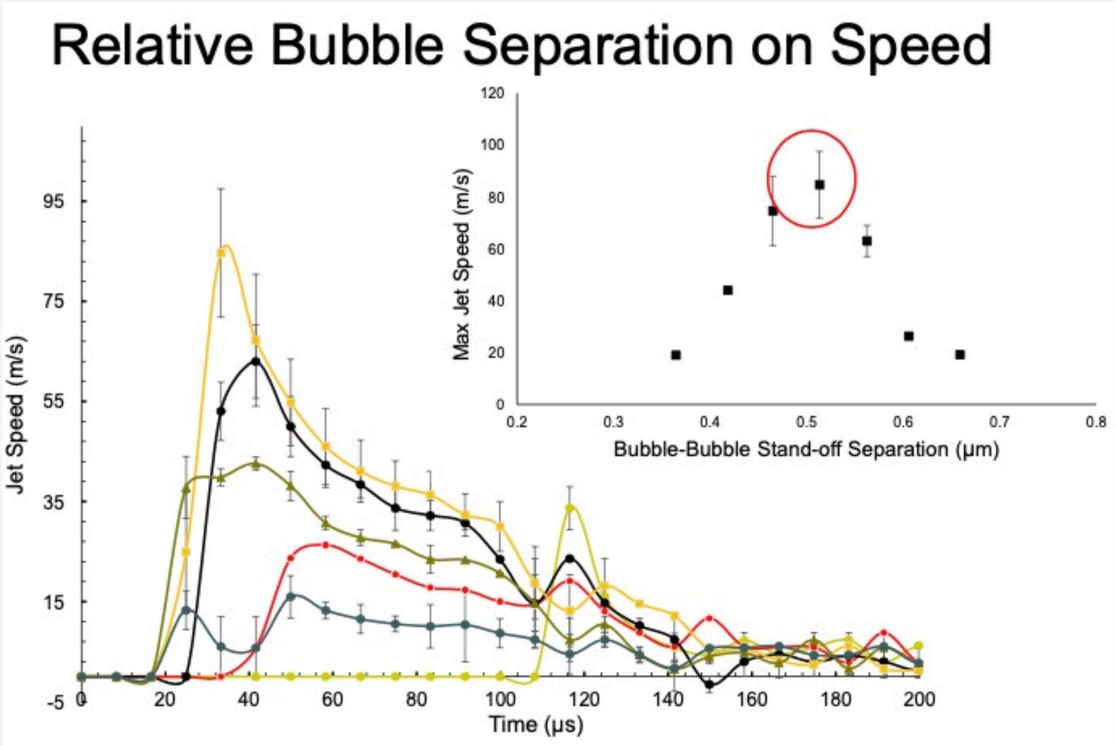




LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

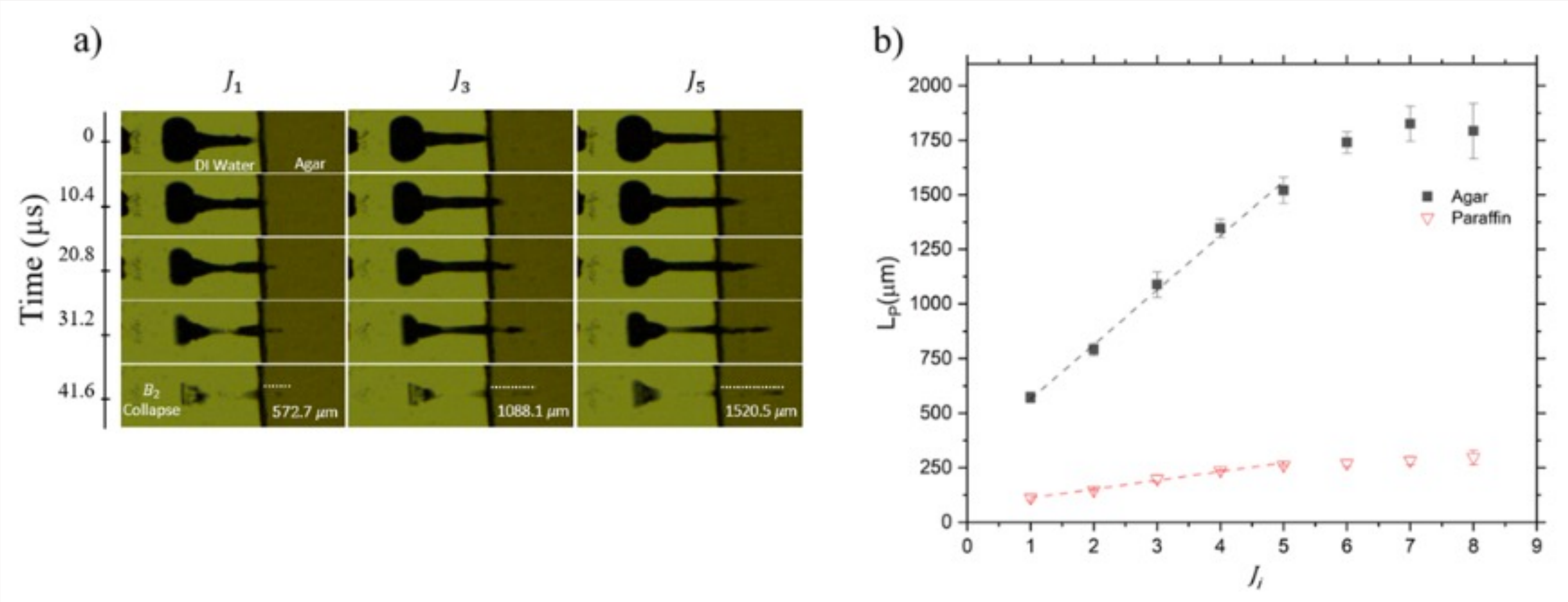
Results





LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Results



LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Surfaces and Interfaces 29 (2022) 101692

Contents lists available at ScienceDirect

Surfaces and Interfaces

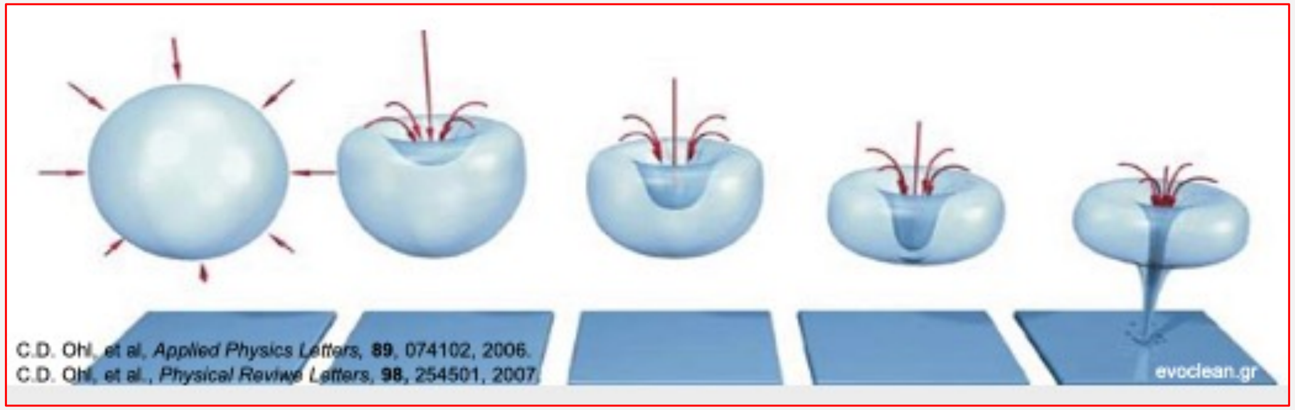
journal homepage: www.sciencedirect.com/journal/surfaces-and-interfaces

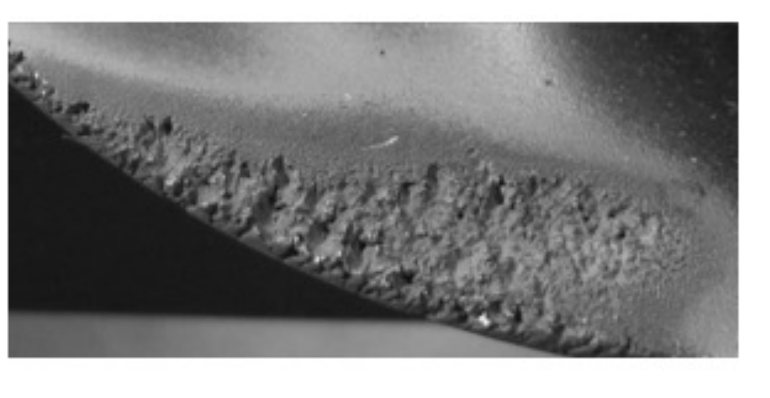
Mitigation of cavitation erosion using laser-induced periodic surface structures

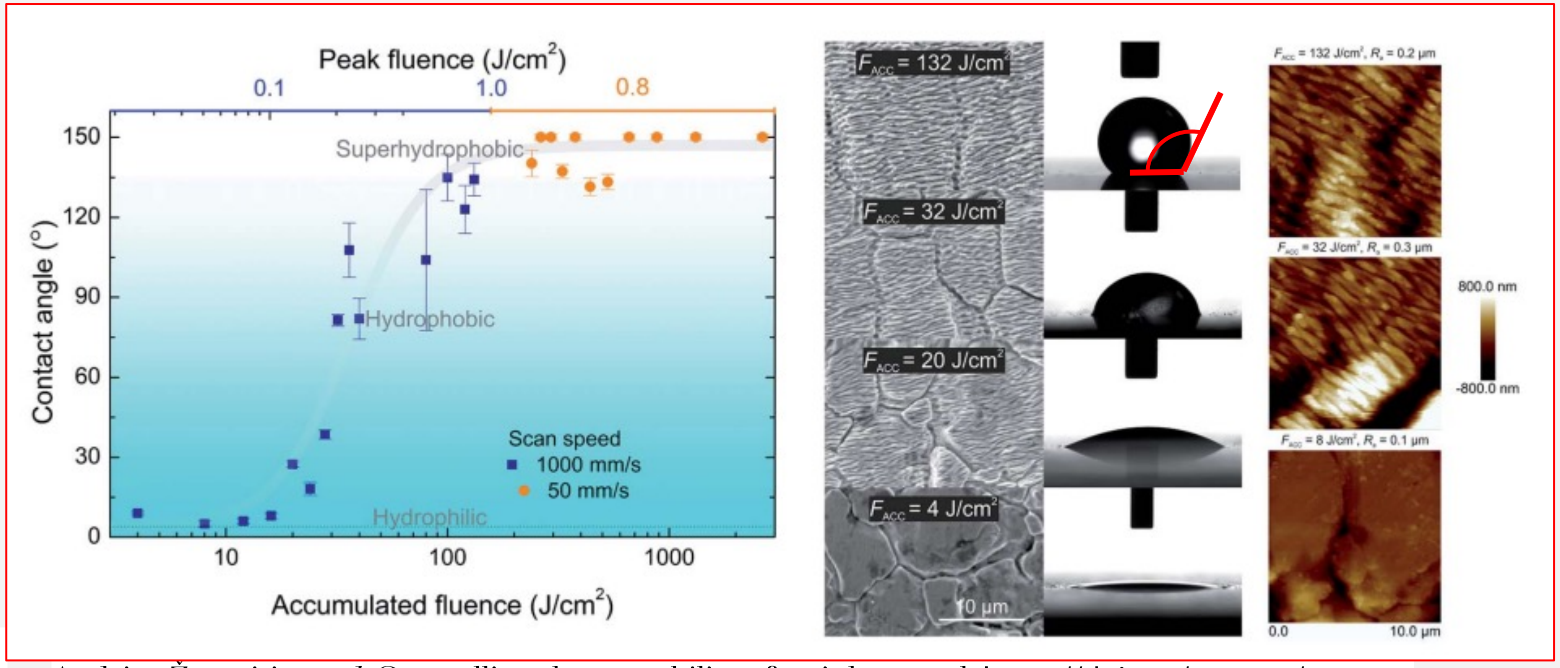
Juan Carlos Gonzalez-Parra [a], Vicente Robles [a], Luis Felipe Devia-Cruz [b], Rene I. Rodriguez-Beltran [b], Natanael Cuando-Espitia [c,*], Santiago Camacho-Lopez [b,*], Guillermo Aguilar [a,*]

[a] *Department of Mechanical Engineering, University of California Riverside, CA, United States*
[b] *Departamento de Óptica, Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, México*
[c] *CONACyT, Applied Physics Group, DICIS, University of Guanajuato, Salamanca, Guanajuato 368850, Mexico*

LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES





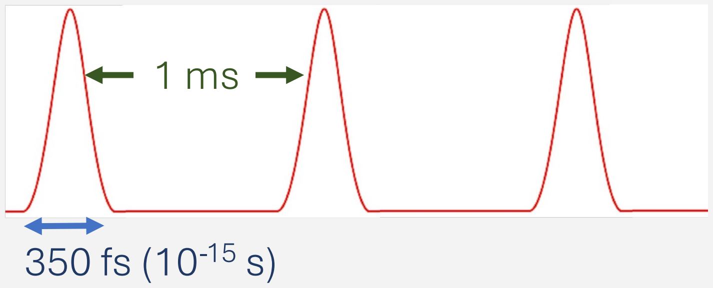


LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES

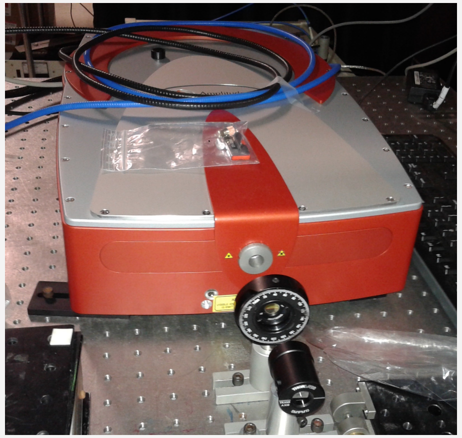
Andrius Žemaitis *et al*. Controlling the wettability of stainless steel. https://doi.org/10.1039/D0RA05665K

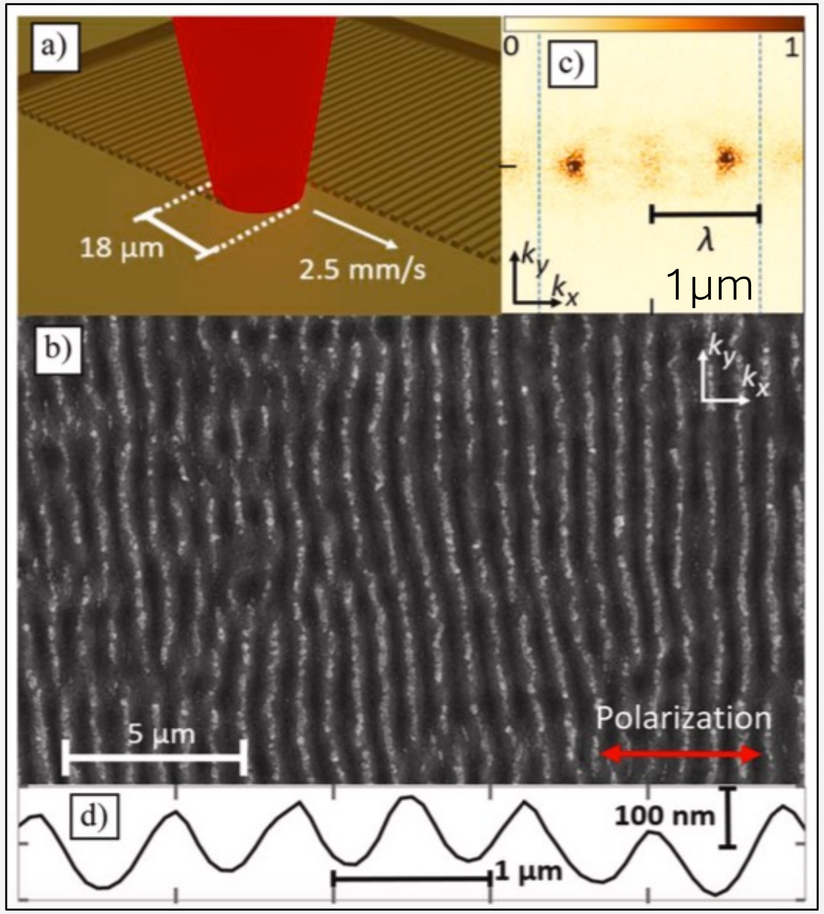
Laser patterning of the surface

Ablation threshold = 0.9 J/cm^2



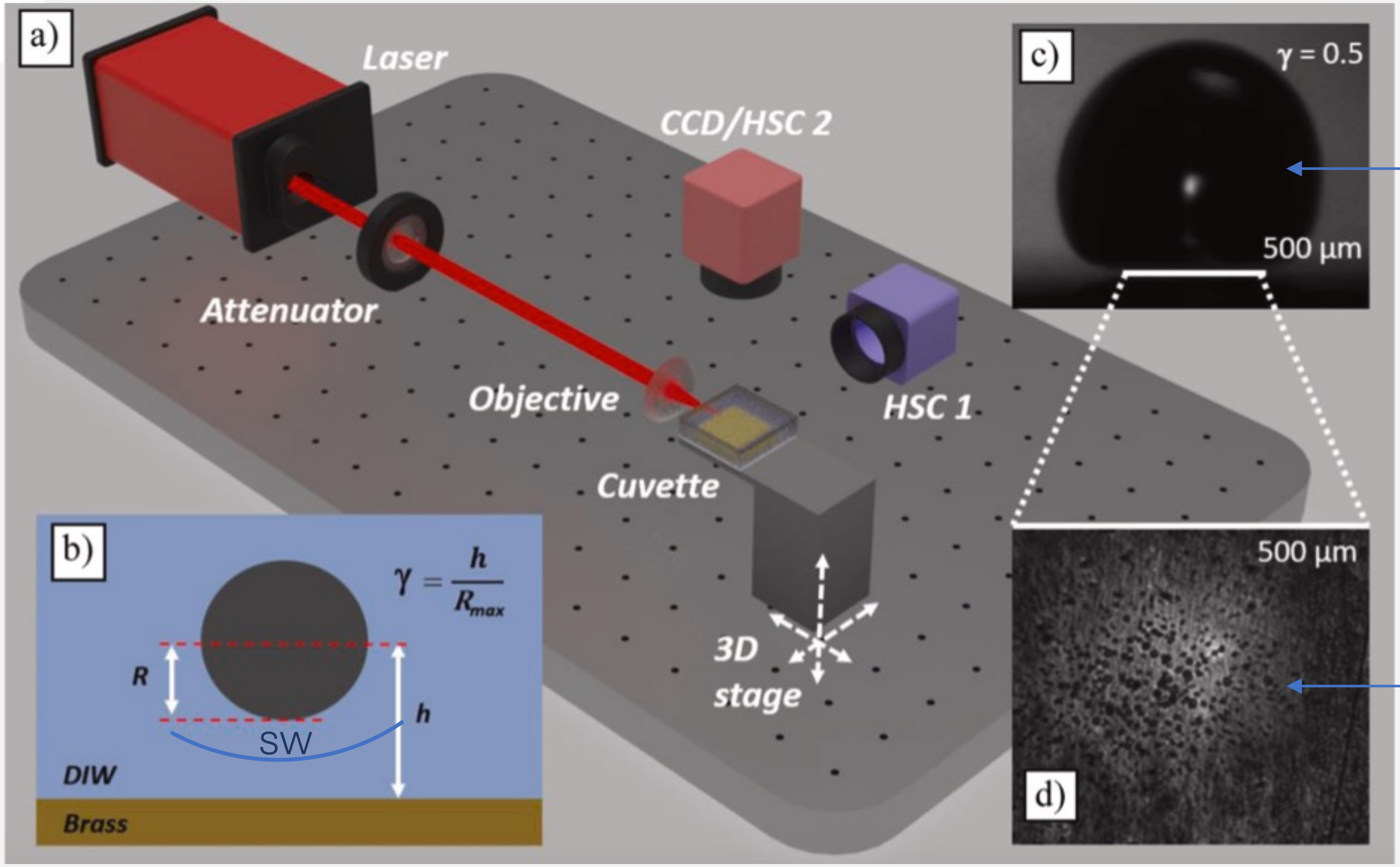
Beamwaist [1/e^2]: 18 um
Wavelength: 1030nm
Per pulse energy: 27 µJ
Repetition rate : 1 kHz
Speed: 2.5 mm/s
Fluence: 0.78 J/cm^2
Pitch : 22 µm





LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

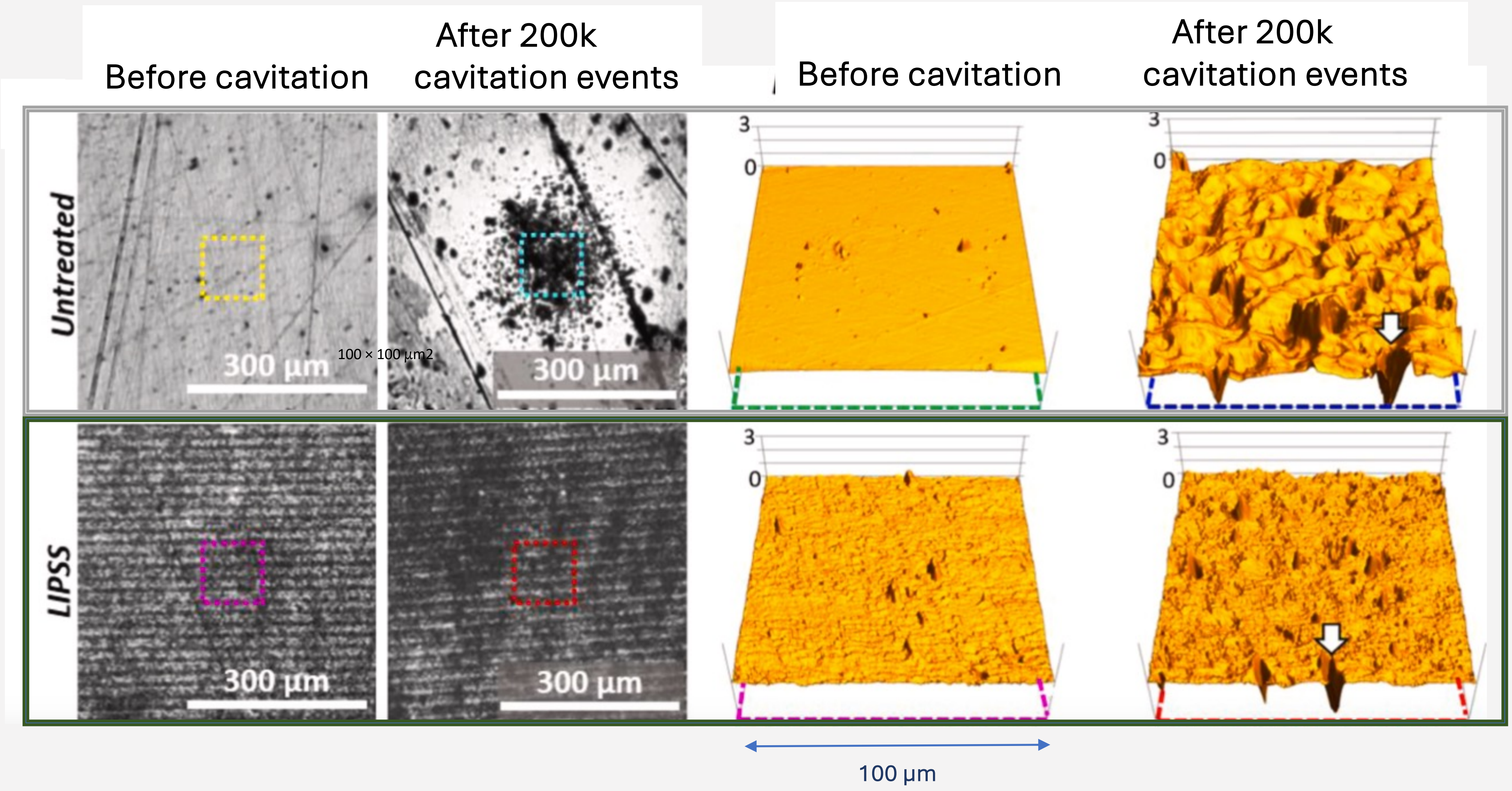
Erosion test through laser-induced cavitation



Cavitation bubble side view

Surface cavitation Erosion pattern

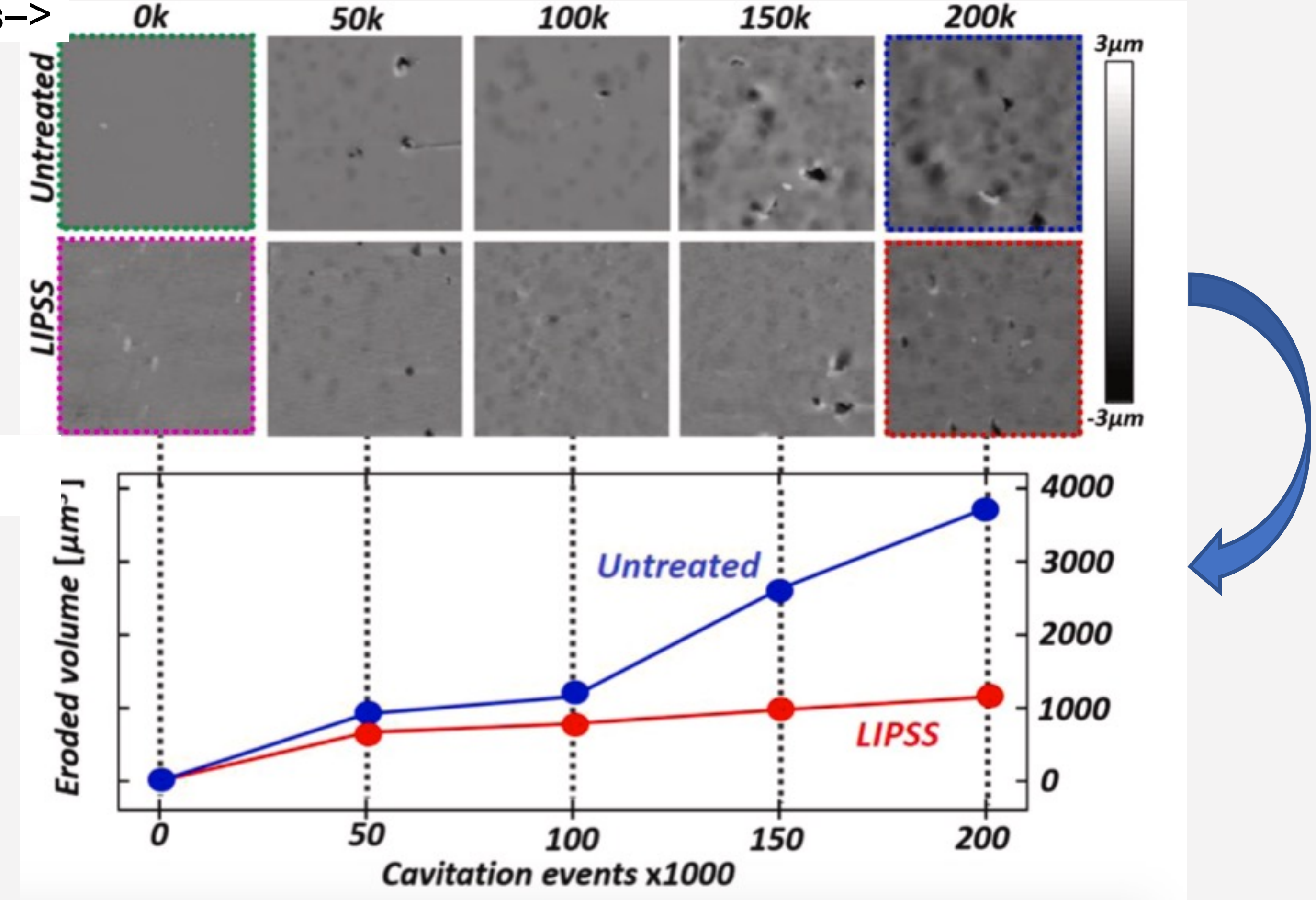
LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES



LÁSERES DE PULSOS ULTRACORTOS Y PROCESAMIENTO DE MATERIALES

Results

Number of cavitation events–>



Final Remarks

Gracias por su atención

ldevia@cicese.mx

LÁSERES DE
PULSOS ULTRACORTOS
Y PROCESAMIENTO DE MATERIALES