DE LA RECHERCHE À L'INDUSTRIE

PHYSICAL MECHANISMS OF ABLATION THRESHOLDS AND PERIODIC STRUCTURE FORMATION FOR METALS UNDER FS AND PS ABLATION

A. Semerok [1], M. Hashida [2]

1 CEA Saclay, DANS/DPC/SEARS/LISL, P.C.56, Gif-sur-Yvette, 91191 CEDEX, France

2 ARCBS, Institute for Chemical Research, Kyoto University, Gokasho,Uji, Kyoto 611-0011, Japan

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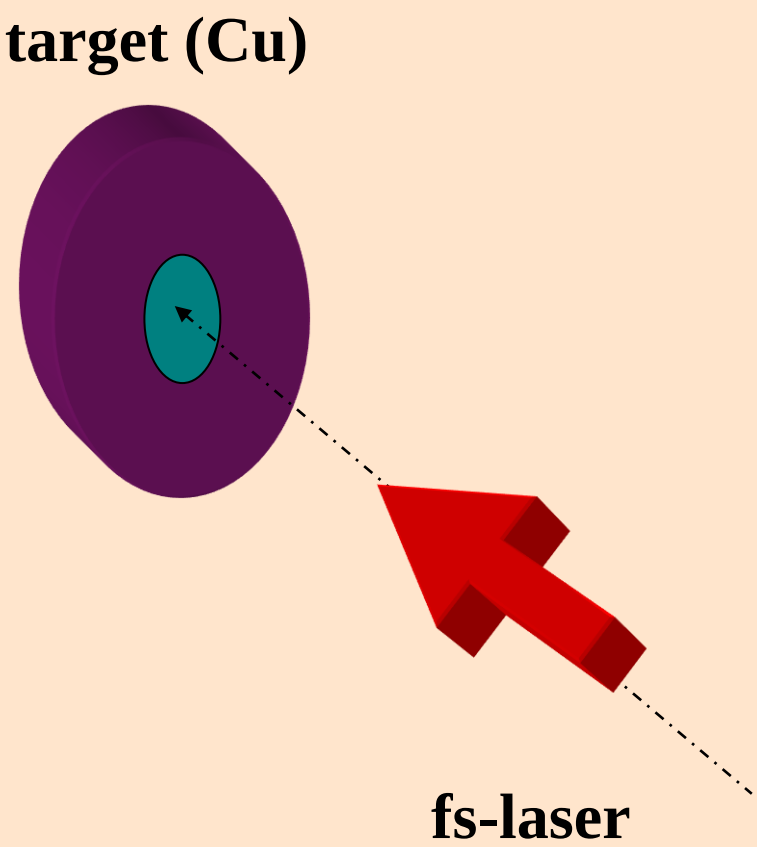
PRESENTATION CONTENT

- ablation thresholds and mechanisms suggested for fs laser “nano-ablation”;

- surface periodic structures;

- towards controllable surface nano-processing and possible applications.

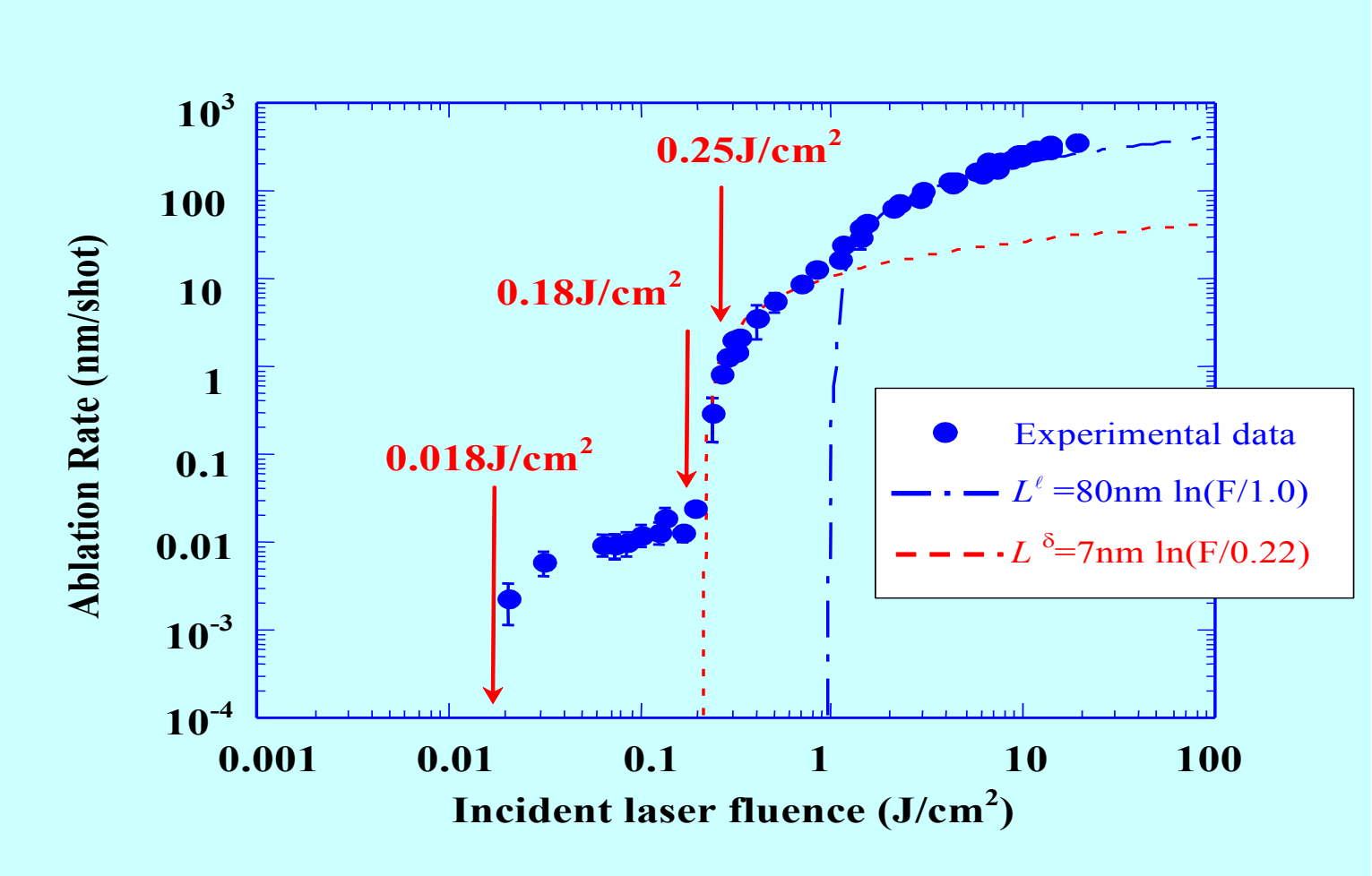
ABLATION THRESHOLD EXPERIMENT



fs-laser pulses:

- 800 nm
- 50 fs -10 ps
- fluence ~(0.01-10) J/cm^2
- (1-10^5) shots
- polarisation

Multi-threshold ablation
(Cu, in air, 800 nm, 60 fs)



[◆] Ablation thresholds of metals with femtosecond laser pulses, Hashida M., Semerok A., Gobert O., Petite G., Wagner J.-F., *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 4423 (2000) pp. 178-185.

[◆] Ablation threshold dependence on pulse duration for copper, Hashida M., Semerok A., Gobert O., Petite G., Izava Y., Wagner J.F., *Applied Surface Science*, 197-198 (2002) pp. 862-867;

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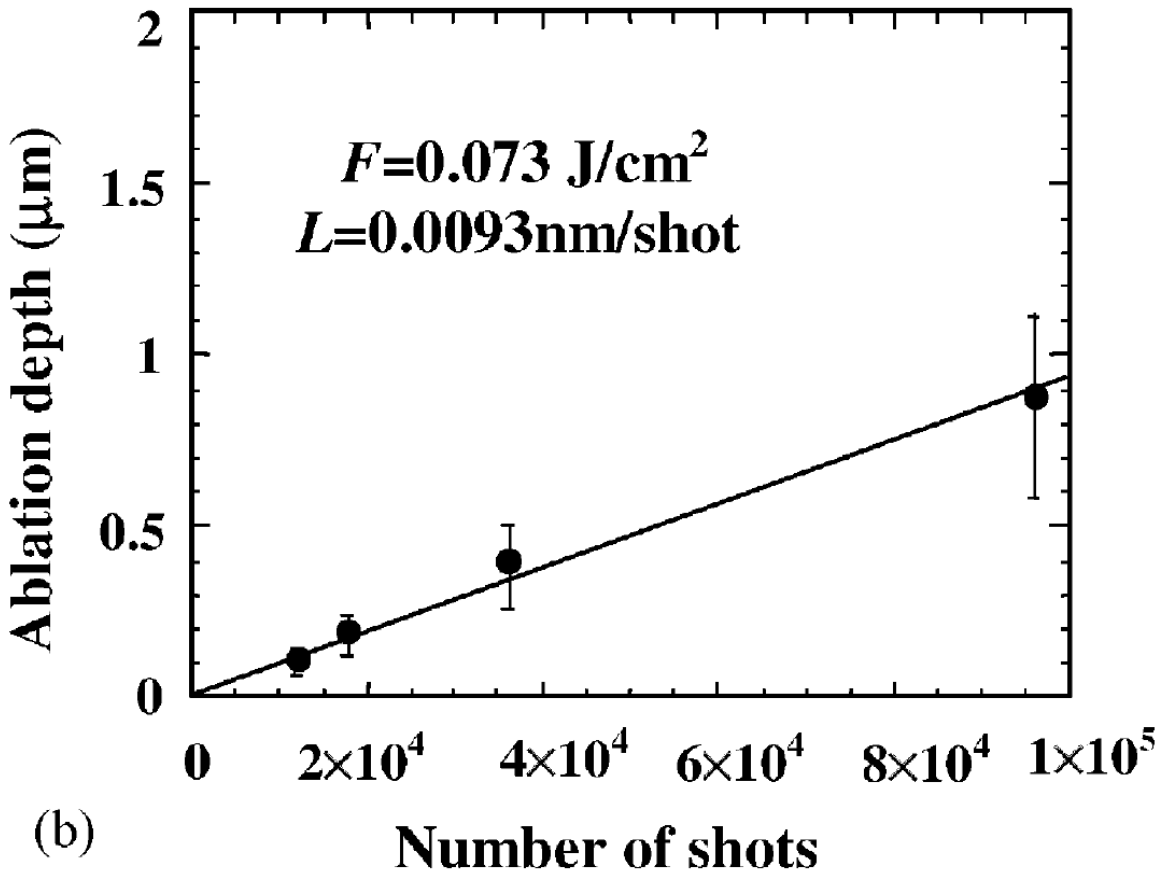

(b)

[◆] Ablation thresholds of metals with femtosecond laser pulses, Hashida M., Semerok A., Gobert O., Petite G., Wagner J.-F., *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 4423 (2000) pp. 178-185.

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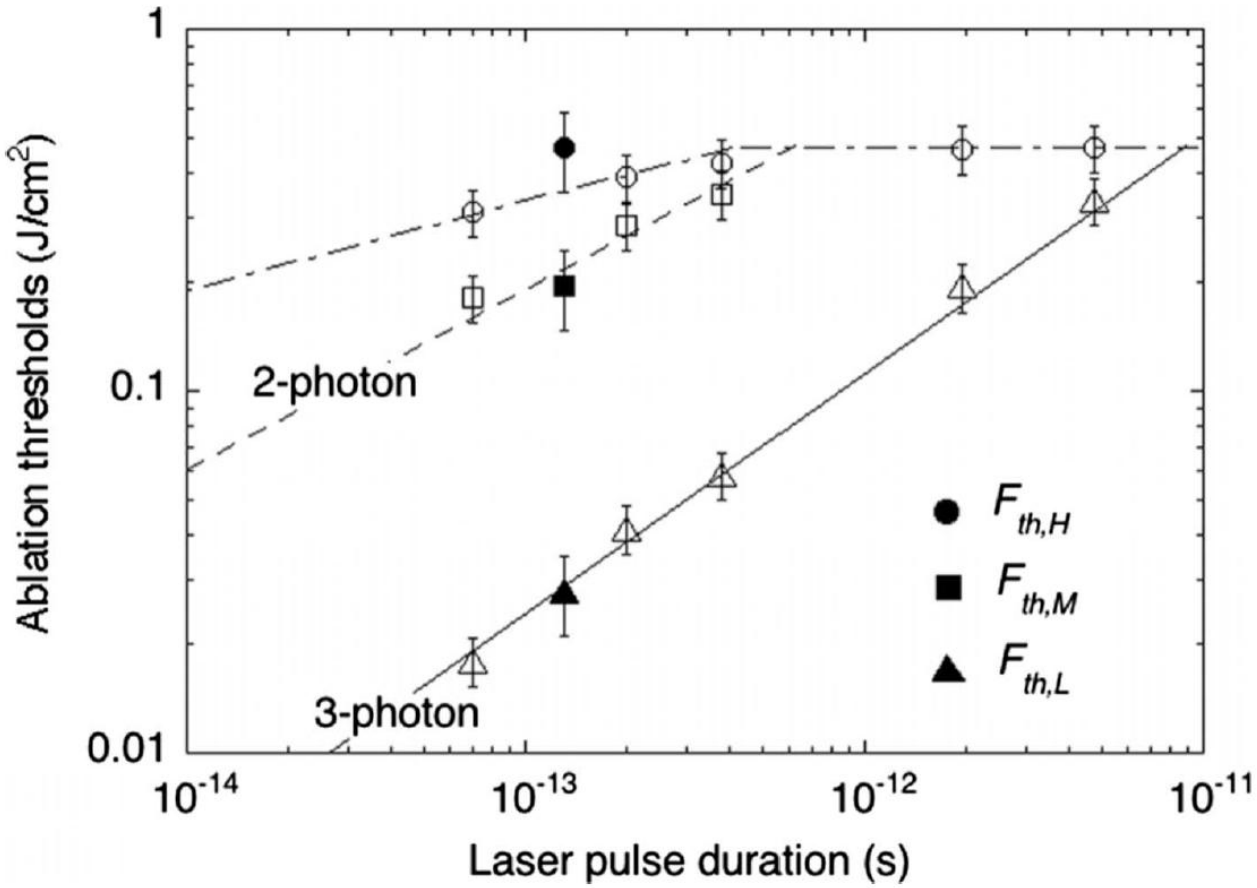
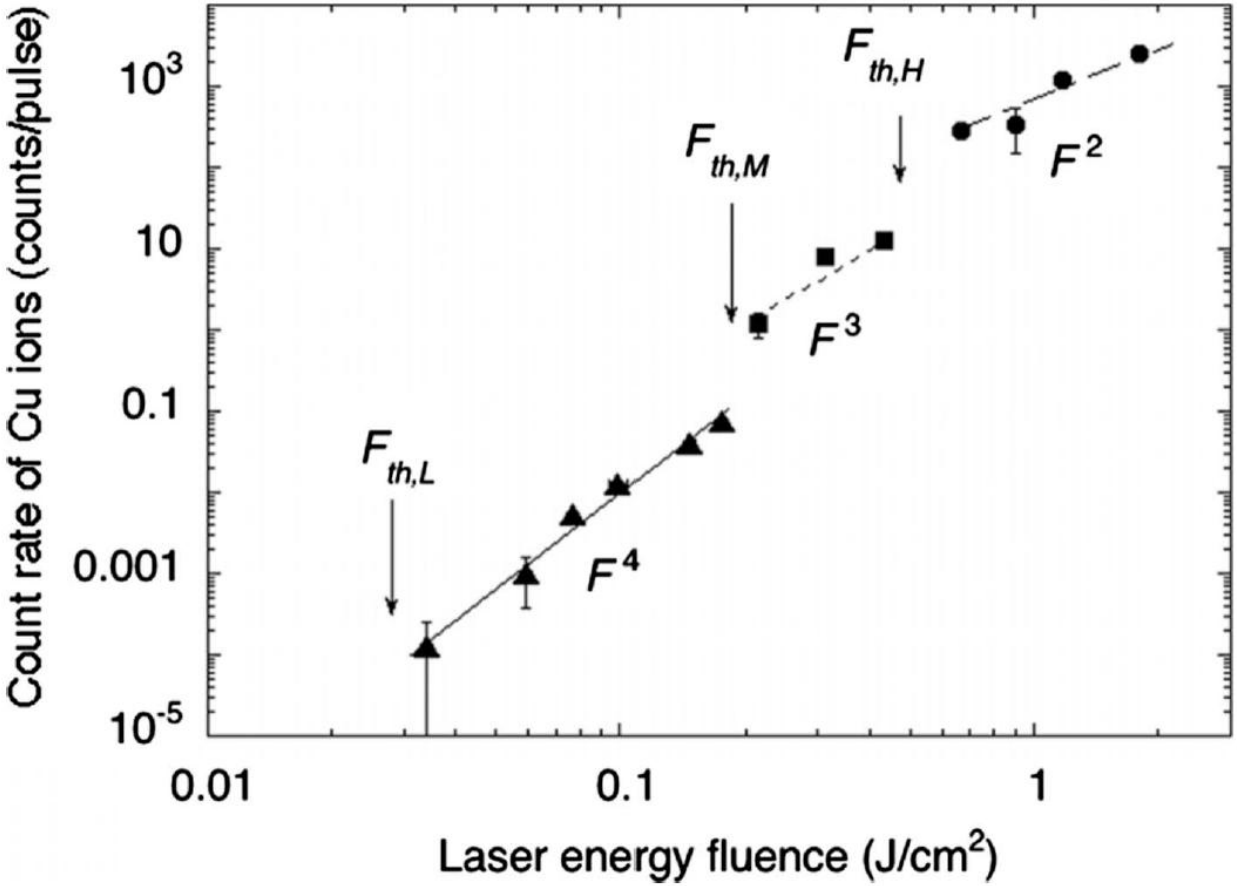
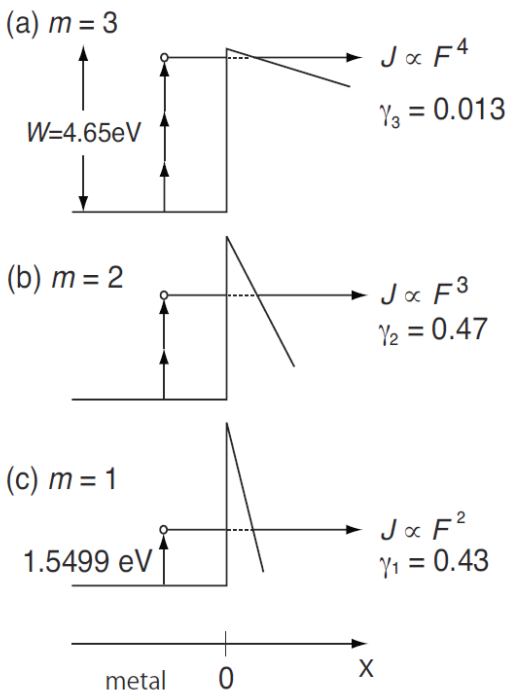


[◆] Ablation thresholds of metals with femtosecond laser pulses, Hashida M., Semerok A., Gobert O., Petite G., Wagner J.-F., *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 4423 (2000) pp. 178-185.

[◆] Ablation threshold dependence on pulse duration for copper, Hashida M., Semerok A., Gobert O., Petite G., Izava Y., Wagner J.F., *Applied Surface Science*, 197-198 (2002) pp. 862-867;

Ion emission
(Cu, 800 nm, 130 fs, 0.028-14.4 J/cm^2)



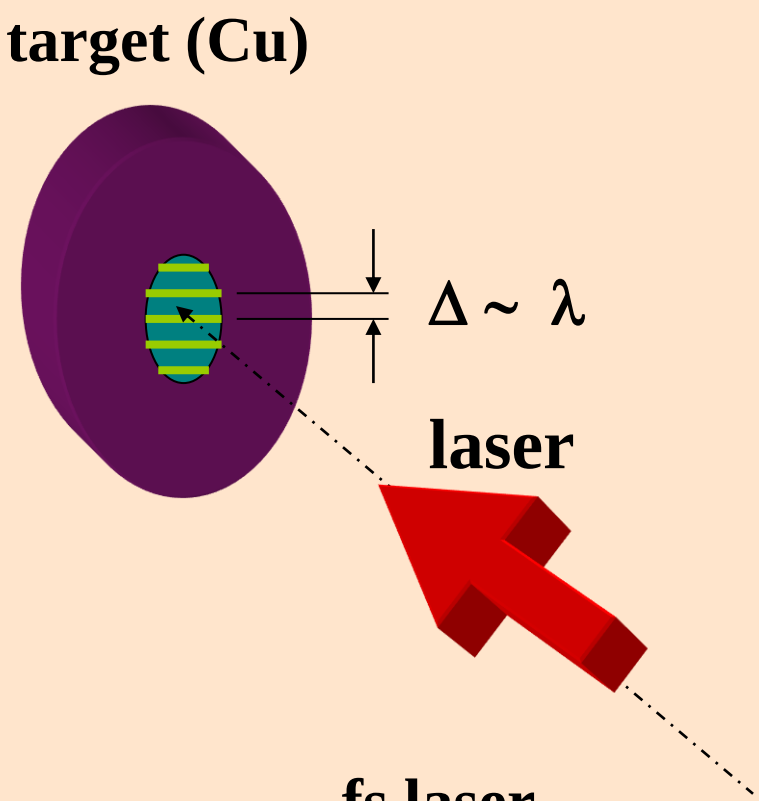


$$\gamma = \frac{\nu_L \sqrt{2 m_e W}}{eE} \leq 1$$

γ is the Keldysh parameter

[◆] Ion emission from a metal surface through a multiphoton process and optical field ionizations, Masaki Hashida, Shin Namba, Kiminori Okamuro, Shigeki Tokita, and Shuji Sakabe, *Phys. Rev.* B 81, 115442 2010;

PERIODIC STRUCTURE EXPERIMENT

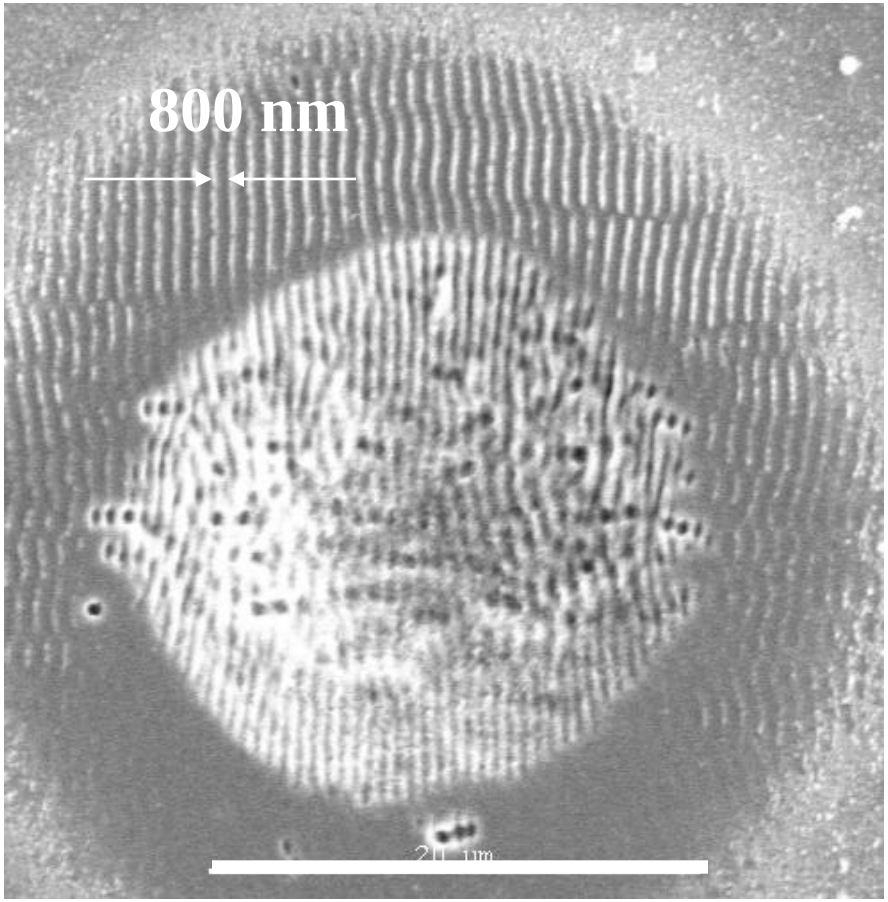


fs laser pulses:

- low fluence (~ J/cm^2)
- multi-shots (10-10^5)
- polarisation

Crater on pure Cu

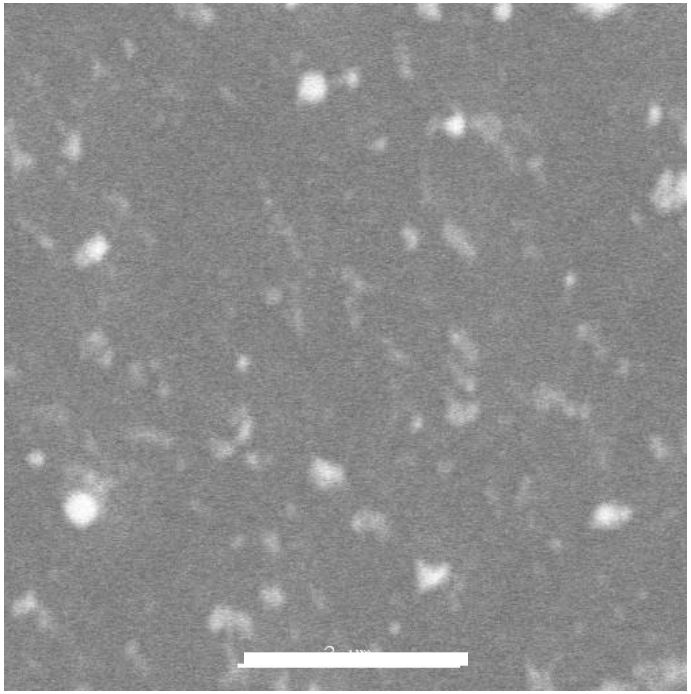
30 shots, 800 nm, 60 fs , F< 1 J cm^{-2}



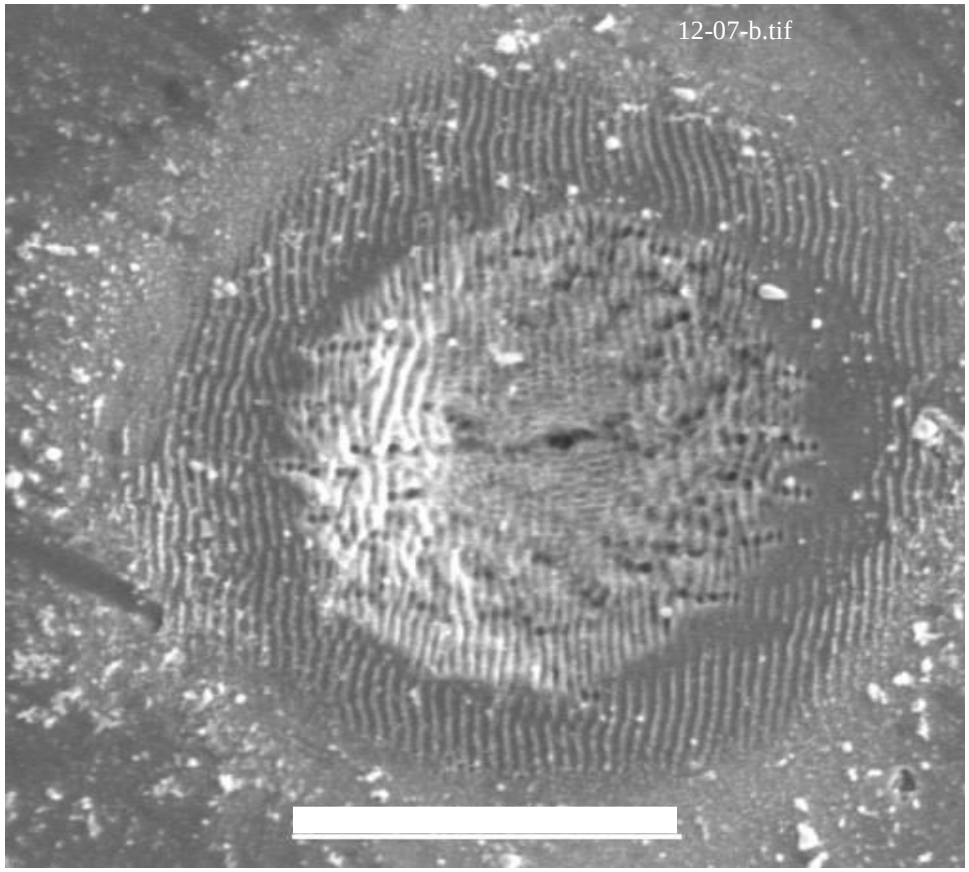
20 µm

Crater on pure Cu

30 shots, 800 nm, 60 fs , F< 1 J cm^{-2}

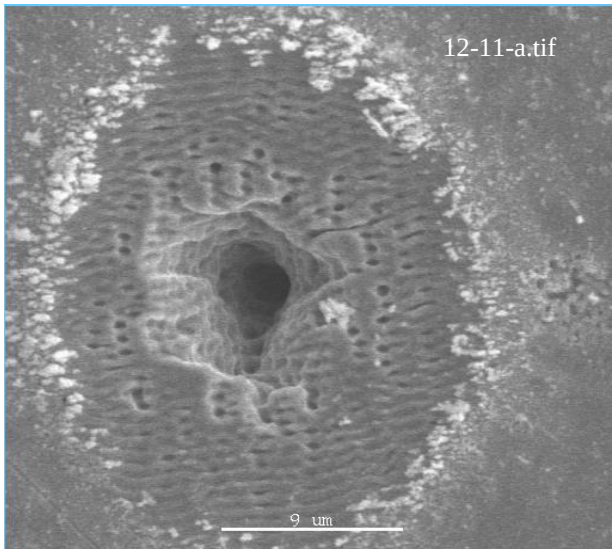


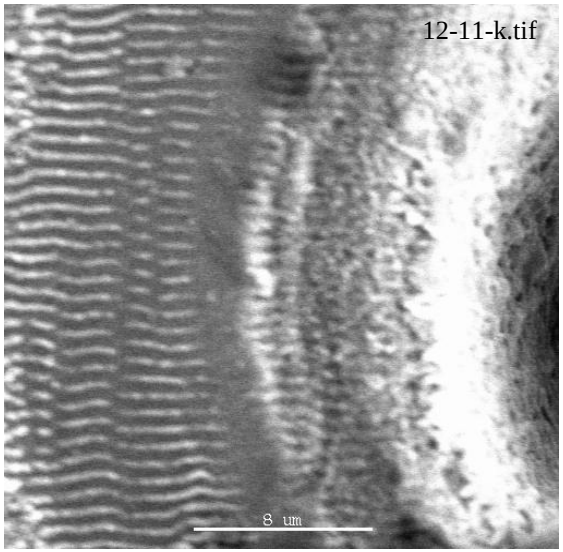
2 µm

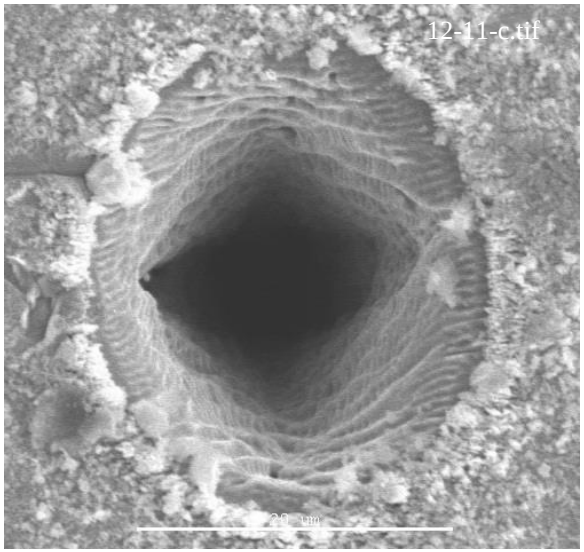


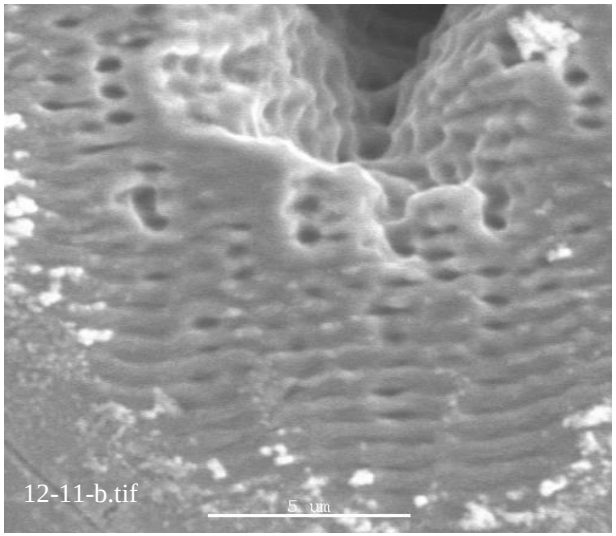
20 µm

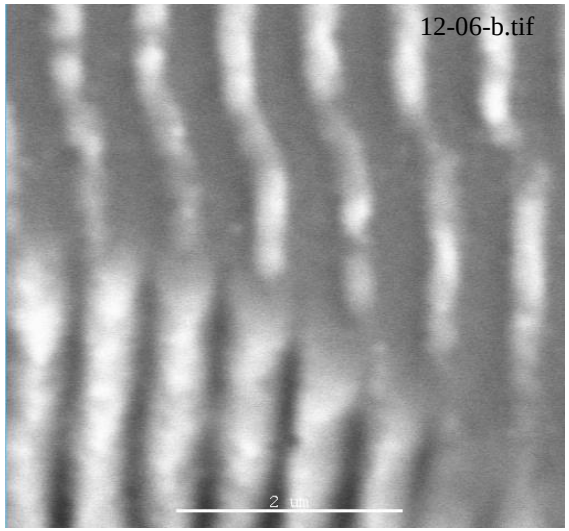
Pure Cu, 800 nm, 60 fs

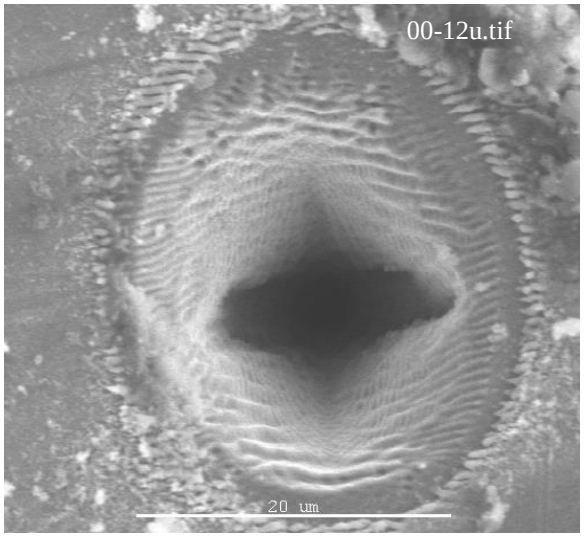






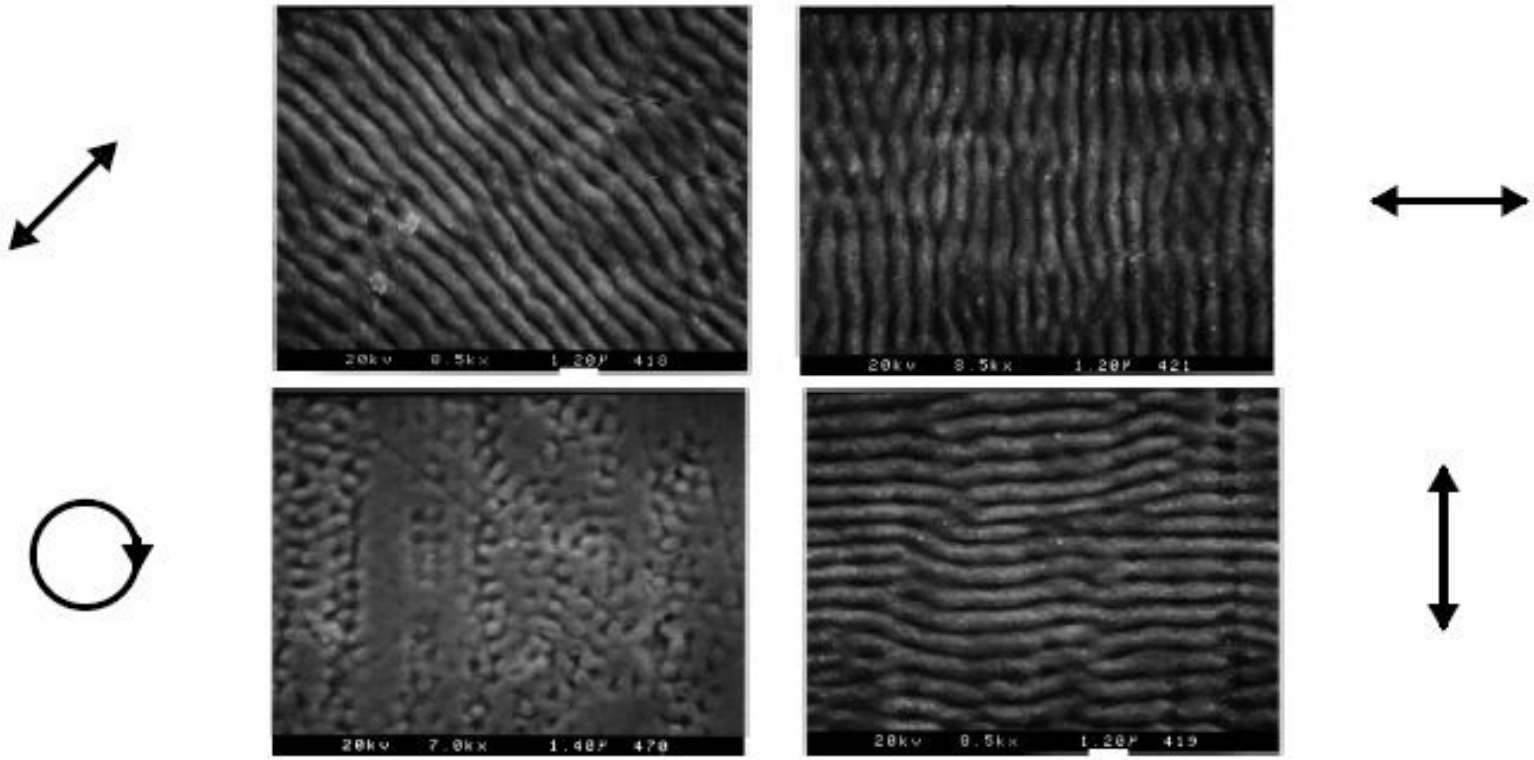






POLARISATION

The direction of the periodic structure depends on the polarization.

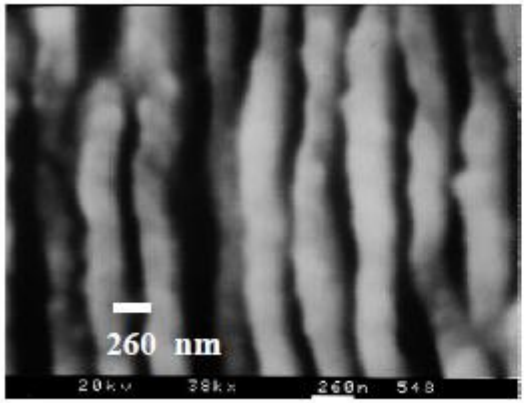


Models for periodic structure formation

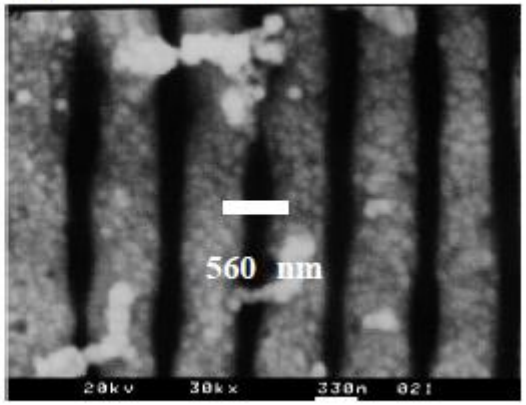
[◆] **Periodic Structure of Metals with Femtosecond Laser Ablation,** Hashida M, Fujita M, Tsukamoto M, Semerok A, Gobert O, Petite G, Izawa Y, and Wagner J F 2003 Proc. of SPIE 4830, p.452.

A periodic structure at the crater bottom in Cu was observed.
The spacing of the patterned structure was depending on the laser fluence.

(*a*) F=0.07 J/cm^2



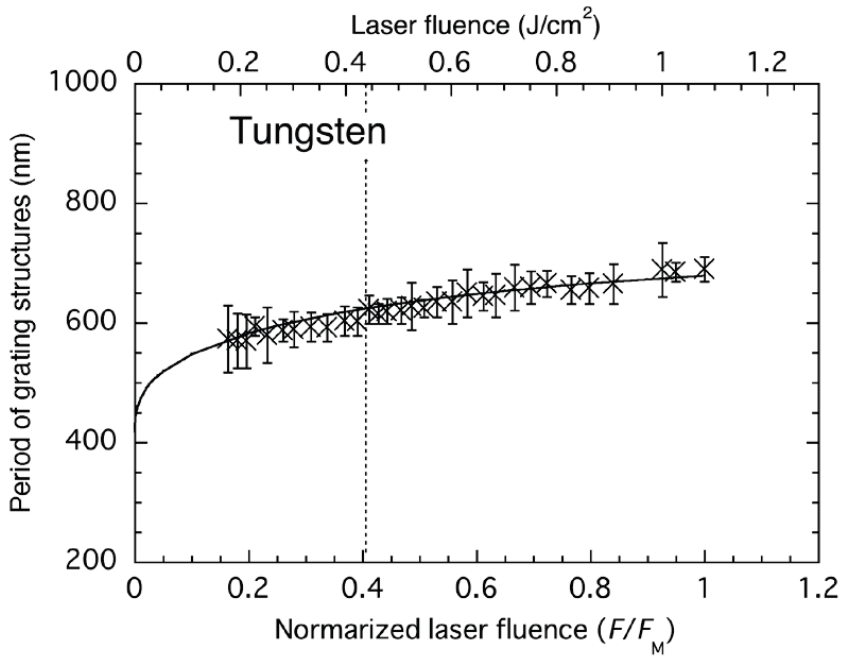
(*b*) F=0.22J/cm^2

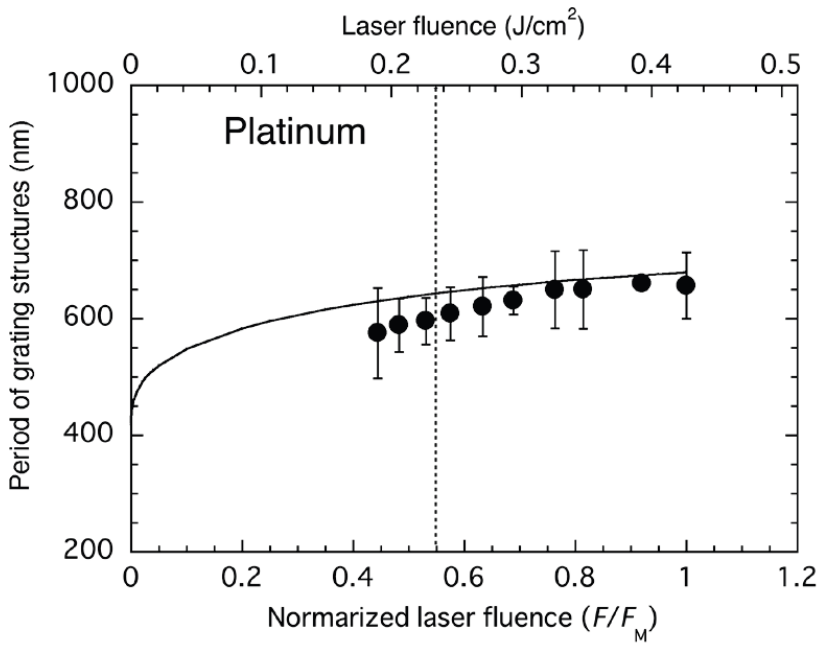


Models for periodic structure formation

[◆] Periodic Nano-Grating Structures Produced by Femtosecond Laser, Pulses for Metals with Low- and High-Melting Points, Masaki HASHIDA, Yasuhiro MIYASAKA, Yoshinobu IKUTA, Kazuto OTANI, Shigeki TOKITA and Shuji SAKABE, *JLMN-Journal of Laser Micro/Nanoengineering* Vol. 7, No. 2, 2012 ;

[◆] Mechanism for self-formation of periodic grating structures on a metal surface by a femtosecond laser pulse, Shuji Sakabe, Masaki Hashida, Shigeki Tokita, Shin Namba, and Kiminori Okamuro, Phys. Rev. B 79, 033409 2009;





Parametric process involving the interaction of laser light and surface plasma waves, as well as the excitation of surface solid-state plasma, has been proposed for the purpose of providing a physical interpretation of the periodical grating structures self-formed on a copper metal surface by femtosecond-pulse laser irradiation.

Models for periodic structure formation

The parametric conditions of $\omega_L = \omega_2 + \omega_{SP}$ and $\mathbf{k}_L = \mathbf{k}_2 + \mathbf{k}_{SP}$, where the subscripts L, 2, and SP indicate incident laser light, scattered light, and surface plasma wave, respectively, are reduced to

$$\omega_L - \omega_{SP} = ck_{SP} - ck_L, \quad \omega_L = ck_L,$$

$$\omega_{SP}{}^2 = c^2 k_{SP}{}^2 + \frac{1}{2}\omega_p{}^2 - \left(c^4 k_{SP}{}^4 + \frac{1}{4}\omega_p{}^2\right)^{1/2}.$$

Wavelength of the plasma waves λ_{SP} :

$$\frac{\lambda_{SP}}{\lambda_L} = \left\{1 + \left(\frac{\omega_p{}^2}{\omega_L{}^2} - 2\right)^{-1}\right\}^{-1/2}$$

[◆] Mechanism for self-formation of periodic grating structures on a metal surface by a femtosecond laser pulse, Shuji Sakabe, Masaki Hashida, Shigeki Tokita, Shin Namba, and Kiminori Okamuro, Phys. Rev. B 79, 033409 2009;

Models for periodic structure formation

[◆] Surface ripples on silicon and gallium arsenide under picosecond laser illumination, P. M. Fauchet and A. E. Siegman, Appl. Phys. Lett. 40(9), 1 May 1982, pp. 824-826;

[◆] Formation of periodic surface structures on film coatings, V. N. Anisimov, V. P. Kozolupenko, and A. Yu. Sebrant, Sov. J. Quantum Electron. 16 (6), June 1986, pp. 848-849;

[◆] High-Intenslty laser irradiation of metallic surfaces covered by periodic structures, L Ursu, I. N. Mihailescu, A. M. Prokhorov, V. N. Tokarev, and V. I. Konov, J. Appl. Phys. 61 (7). 1 April 1987, pp. 2445-2457;

[◆] The nonlinear stage in the growth of laser-induced periodic surface structures, L. A. Bol'shov, A. V. Moskovchenko, and M. I. Persiantsev, Sov. Phys. JETP 67 (4), April 1988, pp. 683-690;

[◆] Formation of periodic surface structures by ultrashort laser pulses, M. B. Agranat, S. I. Ashitkov, and V. E. Fortov, S. I. Anisimov, A. M. Dykhne, P. S. Kondratenko, JETP 88 (2), February 1999, pp. 370-377.

[◆] Effects of electron-phonon coupling and electron diffusion on ripples growth on ultrafast-laser-irradiated metals, J. P. Colombier, F. Garrelie, N. Faure, S. Reynaud, M. Bounhalli, E. Audouard, R. Stoian, and F. Pigeon, J. Appl. Phys. 111, 024902 (2012).

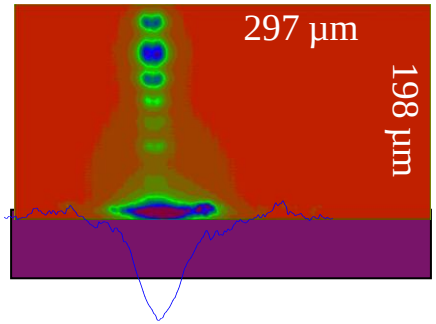
[◆] Publications of J. Reif and this workshop oral presentations;

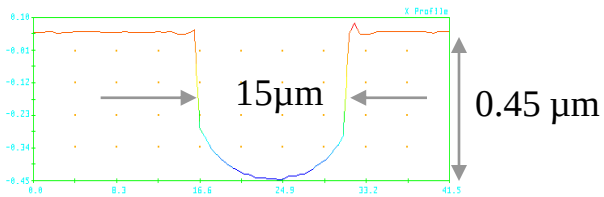
[◆] Poster presentation of C.Z. Antoine “Metallic surfaces under high field: is there common feature between laser exposed surface and RF exposed surfaces” and related model on “surface capillary wave” (see G.N. Fursey, "Field emission processes from a liquid-metal surface". Applied Surface Science, 1997. **215**(1-4): p. 113-134).

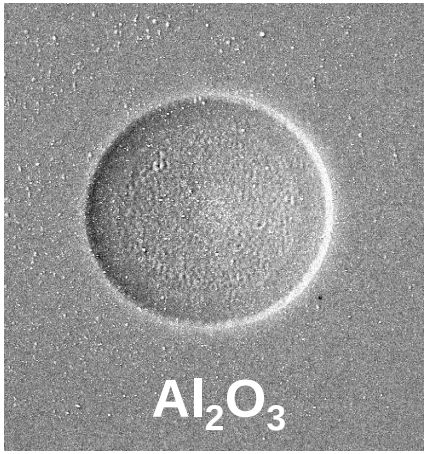
Applications

Laser ablation properties:

- direct interaction with target;
- high ablation efficiency;
- reduced thermal damage;
- proper crater surface;
- increased spatial resolution;
- a lower threshold;
- non-linear interaction.

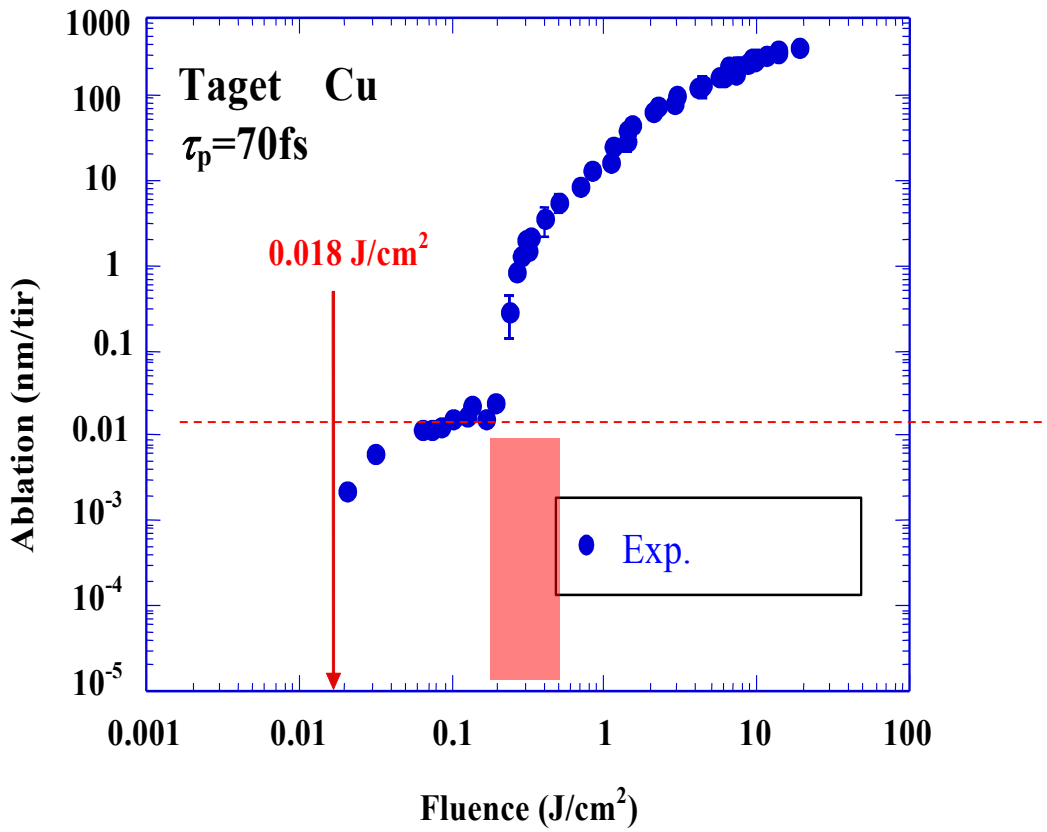




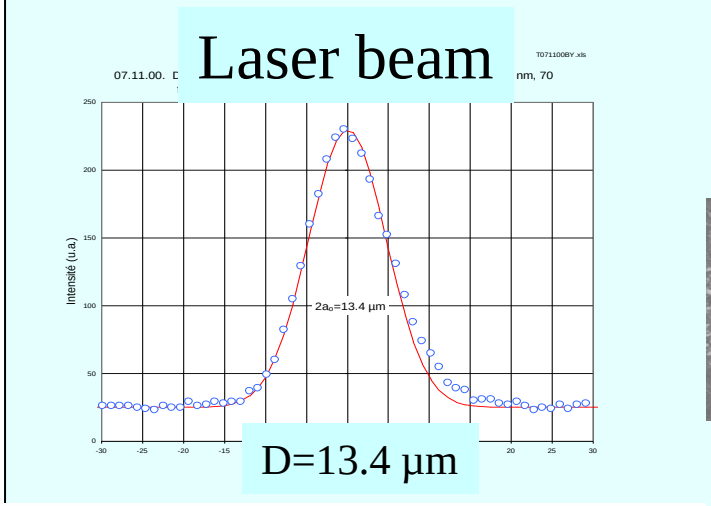


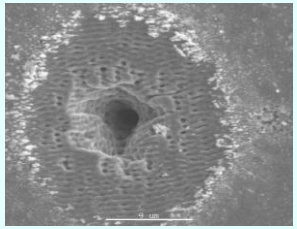
Applications

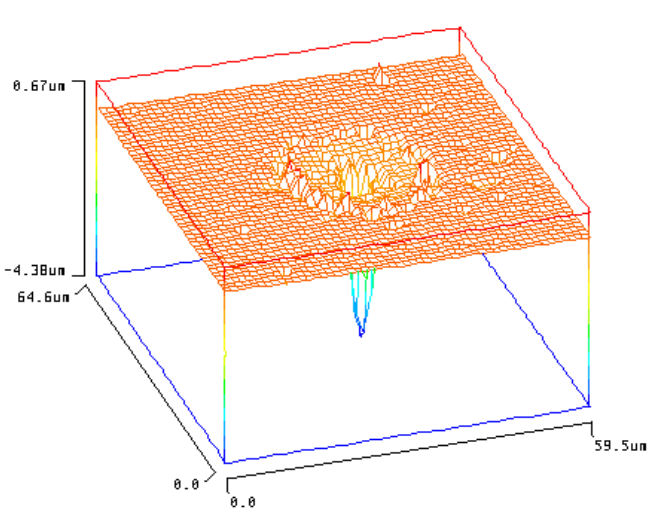
Ablation layer per atomic layer

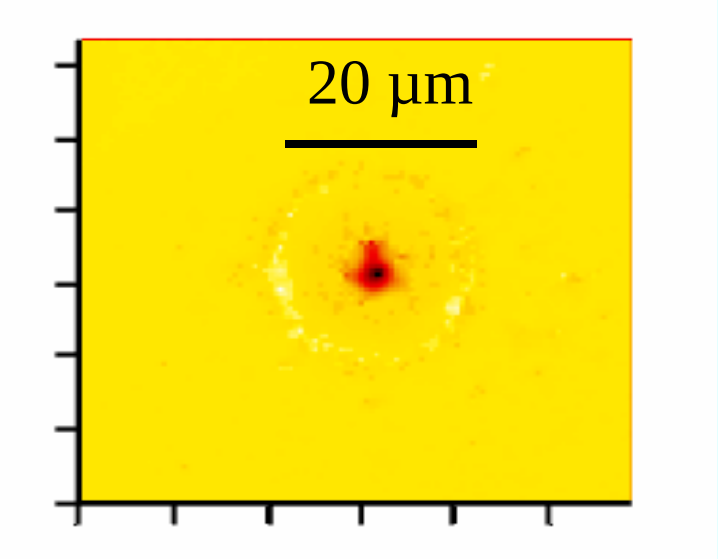


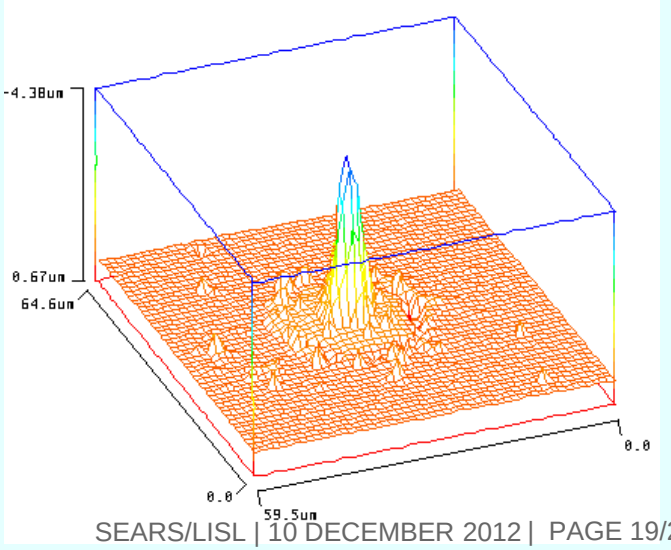
Enhanced spatial resolution
(less than beam diameter)





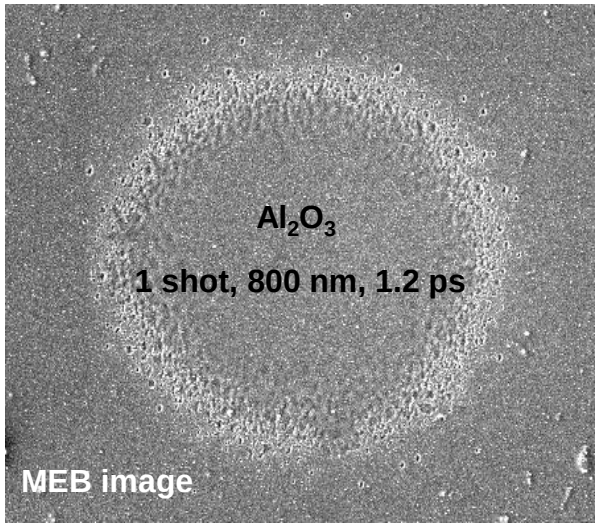


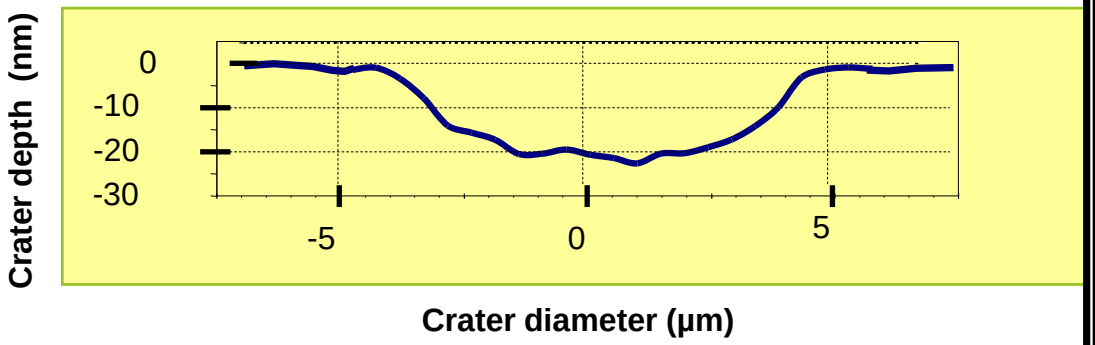




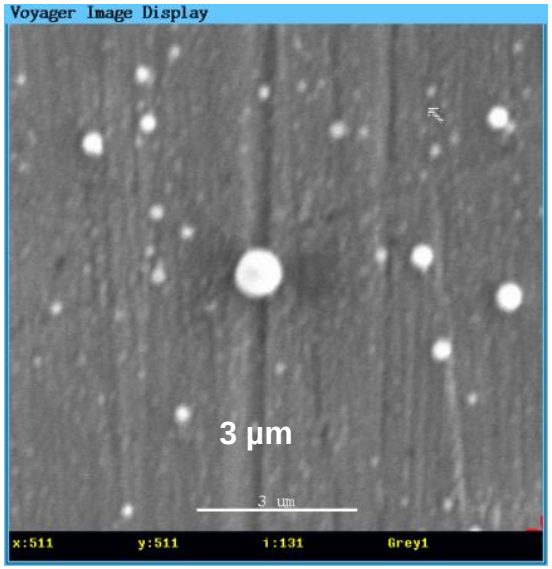
in-depth resolution

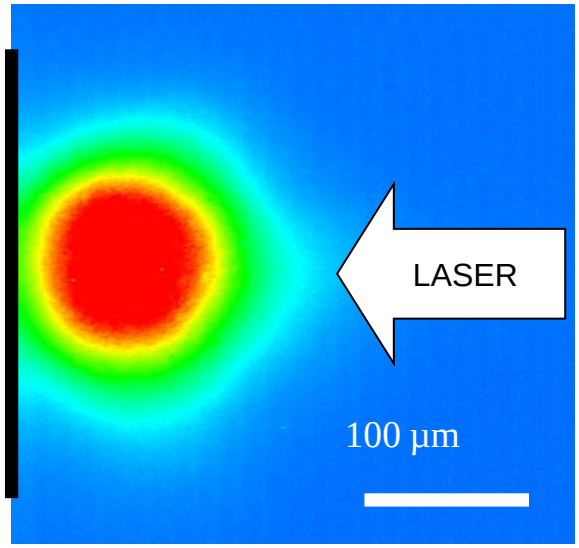
Nanometric resolution





laser plasma → source of nano-particles





Acknowledgements

LUCA-team (DSM/IRAMIS/SPAM, CEA Saclay)

Merci de votre attention!

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33 (0)1 69 08 87 25

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