# Investigation of the role of radial extrusion on the formation of high-aspect ratio nanocavities in condensed matter by XFEL

T. Pikuz[1], S. Makarov[2], V. Zhakhovsky[2], S. Grigoriev[2], P. Chuprov[3], N. Inogamov[2,4], V. Khokhlov[2,4], Yu. Petrov[4], E. Perov[2], V. Shepelev[3], T. Shobu[5], A. Tominaga[5], L.Rapp[6], S. Juodkazis[7,8], M. Makita[9], M. Nakatsutsumi[9], T. R. Preston[9], K. Appel[9], Z. Konopkova[9], V. Cerantola[9,10], E. Brambrink[9], J-P. Schwinkendorf[9], I. Mohacsi[9], V. Vozda[11], V. Hajkova[11], T. Burian[11], J. Chalupsky[11], L. Juha[11], N. Ozaki[12], R. Kodama[12,13], U. Zastrau[9], A.V. Rode[6], S. Pikuz[14]
[1] OTRI, Osaka University, [2]Joint Institute for High Temperatures RAS, [3]Institute for Computer Aided Design, RAS, [4]Landau Institute for Theoretical Physics RAS, [5]The facility at Material Science Research Center, JAEA,Japan, [6]Laser Physics Centre, Australian National University, [7]School of Science, Swinburne University of Technology, [8]School of Materials and Chemical Technology, Tokyo Institute of Technology, [9]European XFEL, [10]Università degli Studi di Milano Bicocca, [11]Institute of Physics, Czech Academy of Sciences, [12]Graduate School of Engineering, Osaka University, [13]Institute of Laser Engineering, Osaka University, [14]HB11 Energy Holdings
e-mail (speaker): pikuz.tatiana@gmail.com

In the recent experiment at the High Energy Density (HED) instrument of the European X-ray Free Electron Laser (EuXFEL) after single shot exposure of LiF crystal by the tightly focused beam (photon energy 9 keV, energy 27-80 μJ, duration ~ 20 fs) the formation of the microchannel with > 1000 length-to-diameter aspect ratio was observed [1]. The presence of cavity in the channel was confirmed by confocal scanning microscope in the fluorescence mode trough measurement of LiF photoluminescence (PL) [2] (Fig. 1a, b) and FIB-SEM (Focused Ion Beam - Scanning Electron Microscopy) technology.

The development of the cavity was analysed via 2D SPH (Smooth Particle Hydrodynamic) and Molecular Dynamic (MD) simulations, revealing a sequence of processes, that lead to the final long cavity structure, with a critical role played by energy deposition through cylindrical rarefaction waves (Fig. 1c,d). We show that the described mechanisms can be applied to any type of materials since the cavity represents a rapidly created a high energy density region with formation of a very high pressure plasma. At such conditions distinctions between material become insignificant.

The formation of nanoscale channels is one of a central component of nanofluidic biochip systems. Our work provides a new pathway for development of new analytical tools with accurate control of liquid fluid flow, high selectivity and increased mass flow rate. The work was partly supported by KAKENHI (Grant No.24K06988) from JSPS.

References

[1] https//doi.org/10.48550/arXiv.2409.03625
[2] T. Pikuz et al, Sci. Rep., 5,17713 (2015)

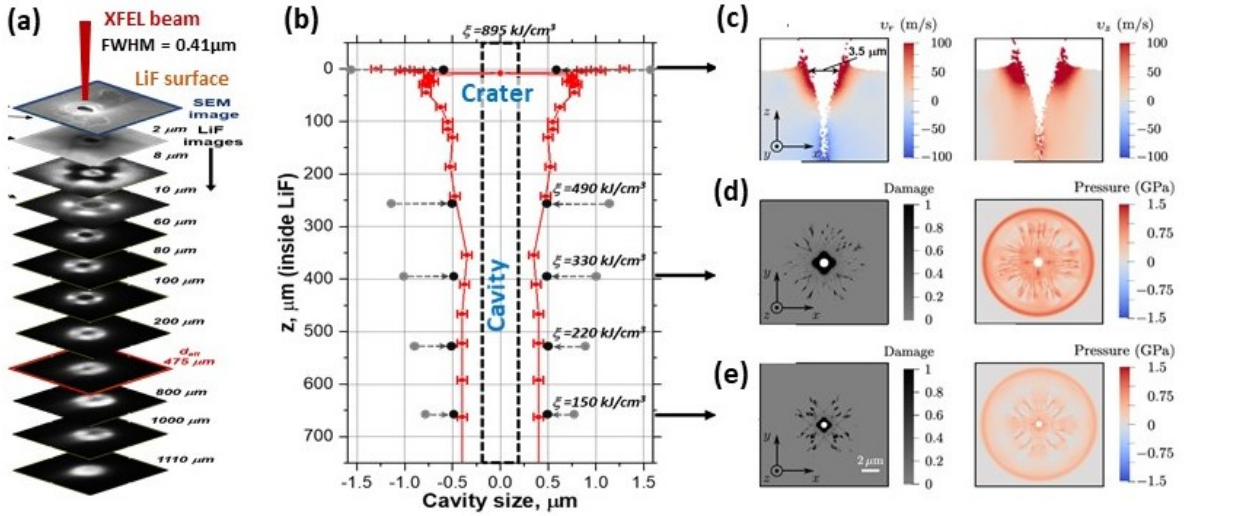


**Figure 1.** Formation of the channel with diameter of ~ 1 μm into the depth down to ~1mm in LiF crystal by single shot XFEL focused beam with the energy density 895 kJ·cm$^{-3}$: (a) in-depth PL images show absence of material in the center (black circles ); (b) dependence of cavity size on the depth: experiment (in red), result of simulation (gray dots), and initial cavity size given in the SPH simulations (dashed-black) ; results of simulations: (c) fields of shock velocities near the LiF surface; damage pattern (d) and pressure fields (e) formed at a depth 390 and 660 μm at time 1.75 ns.