

## **XUV nanosecond laser ablation for pulsed laser deposition of lithium fluoride and caesium iodide**

O. Frolov<sup>1</sup>, K. Kolacek<sup>1</sup>, J. Schmidt<sup>1</sup>, J. Straus<sup>1</sup>, A. Choukourov<sup>2</sup>, P. Pira<sup>3</sup>

<sup>1</sup>*Pulse Plasma Systems Department, Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic*

<sup>2</sup>*Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czech Republic*

<sup>3</sup>*Department of Spectroscopy, J. Heyrovsky Institute of Physical Chemistry of the Czech Academy of Sciences, Prague, Czech Republic*

In this work we demonstrate results of interaction of nanosecond XUV laser pulses at wavelength of 46.9 nm with lithium fluoride (LiF), caesium iodide (CsI) and golden (Au) samples. All of these materials were used for pulsed laser deposition (PLD) on magnesium oxide (MgO) substrate. Samples were irradiated by series with a different number of laser shots at various fluency values. Deposited layers were analysed by optical microscope, atomic force microscope (AFM), X-ray fluorescence (XRF) and finally by X-ray powder diffraction (XRD).

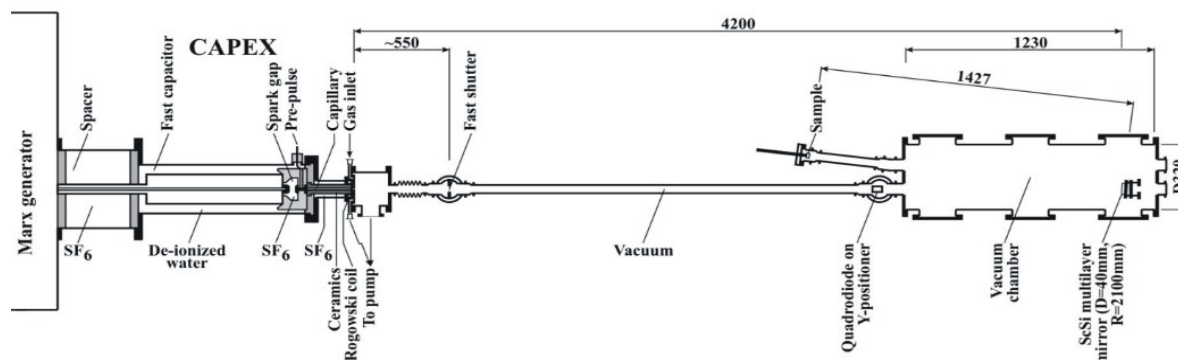
### **Introduction**

Laser ablation of solid surfaces is important in a numerous of applications such as advanced micromachining, surgery, X-ray laser generation, PLD, mass spectrometry of bio-molecules, art cleaning/restoration and fundamental physics studies.

Conventional long wavelength laser very often used for PLD of CsI as a typical ionic crystal [1]. Deposited thin films of CsI could be used as a traditional scintillation detector [2] and relatively stable photocathodes [3]. Production of LiF by PLD technics is very interesting for a variety of reasons. Thin LiF coatings of electrodes could reduce the work function of metal [4] and could improve the performance of organic electroluminescence devices [5]. Recently, some ablation experiments with CsI [6] and LiF [7] by XUV laser (with wavelength of 46.9 nm) has been performed. In this paper we present not only results of ablation of CsI, LiF and Au surfaces, but also analysis of deposited materials on MgO substrate. Samples were irradiated by 2, 5, 10, 20, 40 and 80 laser pulses in the range of energies from 110 to 130  $\mu\text{J}$  (all energies were estimated in a primary beam).

## Apparatus

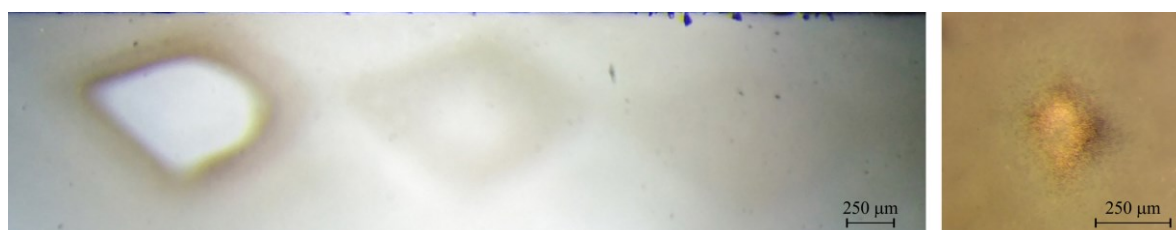
The arrangement of the XUV laser-matter interaction experiments is illustrated in Fig. 1. As a source of intense XUV radiation was used Ne-like Ar capillary discharge laser with wavelength of 46.9 nm. Our driver CAPEX consists of a Marx generator, coupling section, a coaxial line filled with deionized water, self-breakdown spark gap and a ceramic capillary. For ablation and PLD purposes apparatus was extended for vacuum chamber with vacuum photodiode, Sc/Si multilayer mirror (with reflectivity of about 13%) and interaction tube with samples. In more details apparatus CAPEX was described in the early published papers [8]-[10]. Estimation of laser energy was performed from measurements of intensity of XUV radiation with Al filters of different thickness by vacuum photodiode [11]-[12].



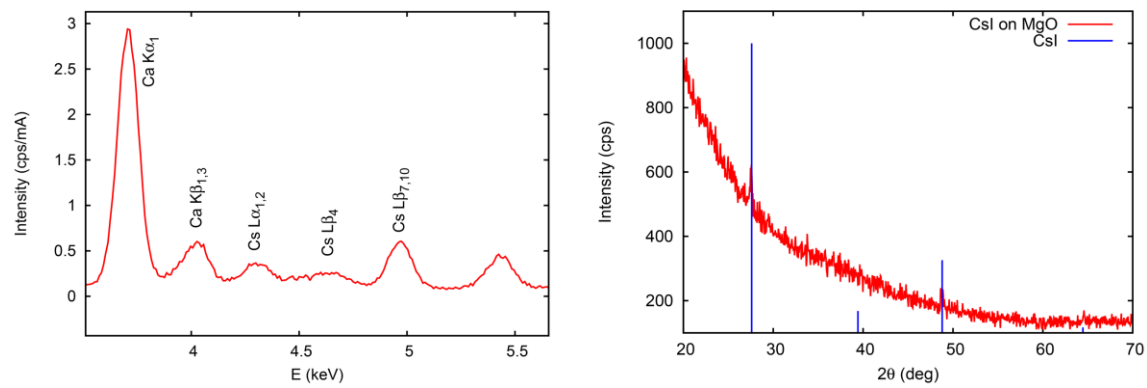
**Fig. 1** Experimental apparatus CAPEX with extension for ablation experiments.

## Results

The LiF, CsI and layer of Au on PMMA (thickness of 50 nm) were deposited on MgO substrate by PLD technics. Substrates were placed at distance about 1 mm from samples and angles between focused laser beam and sample were  $30^\circ$  for Au,  $48^\circ$  for LiF and  $40^\circ$  for CsI. At the first, deposited thin films on MgO substrate were observed by optical microscope (see Fig. 2): Au and CsI deposited layers were clearly visible, but in the case of



**Fig. 2** Deposited films on MgO substrate observed by optical microscope: left – layer of CsI after 80, 40 and 20 laser pulses (from left to right), right – layer of Au after 10 laser pulses.



**Fig. 3** XRF (left) and  $2\theta$  XRD (right) analysis of deposited CsI layer on MgO substrate

LiF situation was quite complicated due to transparency of deposited material and substrate. In the next step, ablation craters on the surface of the LiF and CsI samples were analyzed by AFM and optical surface profiler Zygo based on the white light interferometry. In the case of Au (when the substrate stayed on the same place and the sample was moved), all material was ablated by 10 laser pulses with average energy of  $110 \mu\text{J}/\text{pulse}$  in 10 positions (thickness in each position is about 50 nm) on the sample. Etch rate of LiF sample is decreasing with more pulses up to 9 nm/pulse (for 80 laser shots with average energy of  $119 \mu\text{J}/\text{pulse}$ ). And similar situation was observed on CsI sample when etch rate is decreasing to 17 nm/pulse (for 80 laser shots with average energy of  $113 \mu\text{J}/\text{pulse}$ ). And finally, deposited film of CsI on the MgO substrate was characterized by XRD and XRF conducted with a Rigaku NEX CG spectrometer (Fig. 3). Emission lines on the spectrum with energies of 4.272 keV, 4.286 keV, 4.652 keV, 4.975 keV and 4.989 keV correspond to  $L\alpha_2$ ,  $L\alpha_1$ ,  $L\beta_4$ ,  $L\beta_{10}$  and  $L\beta_7$  transitions of Cs. XRD pattern of deposited CsI thin films prepared by PLD technique is shown in right part of the Fig. 3. The XRD scan exhibits a number of intense and sharp peaks which are assigned to the indicated Bragg reflections from CsI crystal. Deposited CsI layer was presented as a compound at the surface, which was indicated by peaks in the  $2\theta$  spectra. Measured peaks at angles 27.7, 48.7 and 64.4 correspond to the lattice plane (110), (211) and (310) for CsI crystal. When we compare obtained data with data at [13] where XRD patterns were obtained for different thickness of CsI layer, we could estimate thickness of deposited layer of CsI on MgO substrate by PLD technics in range from 20 to 100 nm.

## Conclusions

In this paper we investigated potential use of XUV ablation of Au, LiF and CsI (which is difficult to ablate by UV-Vis-NIR lasers) for PLD purpose. It turned out that deposited layers of Au and CsI

are clearly visible by optical microscope. Analysis of the deposited layer using XRF and XRD shows that PLD of CsI as a compound was successful. Other materials will be analysed in a near future.

**Acknowledgment** This work supported by the Grant Agency of the Ministry of Education, Youth and Sports of the Czech Republic under Contract LG15013.

## References

1. Fernandez-Lima F., Collado V. M., Ponciano C. R., Farenzena L. S., Pedrero E., Da Silveira E. F.: Laser ablation of CsI analyzed by delayed extraction, *Appl. Surf. Sci.*, 217(1-4), 202-209, 2003
2. Nikl M.: Scintillation detectors for x-rays, *Meas. Sci. Technol.* 17, R37-R54, 2006
3. Buzulutskov A., Breskin A., Chehik R., Va'vra J.: Study of photocathode protection with thin dielectric films, *Nucl. Instrum. and Meth.* A371, 147-150, 1996
4. Schlaf R., Parkinson B. A., Lee P. A., Nebesny K. W., Jabbour G., Kippelen B., Peyghambarian N., Armstrong N. R.: Photoemission spectroscopy of LiF coated Al and Pt electrodes, *J. Appl. Phys.* 84, 6729-6736, 1998
5. Hung L. S., Tang C. W., Mason M. G.: Enhanced electron injection in organic electroluminescence devices using an Al/LiF electrode, *Appl. Phys. Lett.* 70, 152-154, 1997
6. Pira P., Zelinger Z., Burian T., Vysin L., Juha L., Lancok J., Danis S., Nverly V., Kudrna P., Tichy M., Grisham M. E., Heinbuch S., Rocca J. J., Wild J.: Ablation of CsI by XUV capillary discharge laser, *Bulletin of APS* 60, 40, 2015
7. Pira, P., Burian, T., Vysin, L., Chalupsky, J., Lancok, J., Wild, J., Strizik, M., Zelinger, Z., Rocca, J. J., et al.: Ablation of ionic crystals induced by capillary-discharge XUV laser, *Proc. SPIE*. 8077, 807719-1-807719-7, 2011
8. Kolacek K., Schmidt J., Straus J., Frolov O., Prukner V., Melich R., Psota P.: Spontaneous and artificial direct nanostructuring of solid surface by extreme ultraviolet laser with nanosecond pulses, *Laser and Particle Beams* 34, 11-22, 2016
9. Kolacek K., Schmidt J., Straus J., Frolov O., Prukner V., Melich R., Choukourov A.: A new method of determination of ablation threshold contour in the spot of focused XUV laser beam of nanosecond duration, *Proc. SPIE* 8777, 87770N-87770N, 2013
10. Frolov O., Kolacek K., Straus J., Schmidt J., Prukner V., Choukourov A.: Application of EUV optics to surface modification of materials, *Proc. SPIE* 8777, 877707-877707, 2013
11. Kolacek K., Schmidt J., Straus J., Frolov O.: Calibration of windowless photodiode for extreme ultraviolet pulse energy measurement, *Applied Optics* 54 [35], 10454-10459, 2015
12. Frolov O., Kolacek K., Schmidt J., Straus J.: Ablation Plume Induced by Laser EUV Radiation, *Springer Proceedings in Physics* 169, 397-403, 2016
13. Triloki, Garg P., Rai R., Singh B. K.: Structural characterization of as-deposited cesium iodide films studied by X-ray diffraction and transmission electron microscopy techniques, *Nuclear Instruments and Methods in Physics Research A* 736, 128-134, 2014