NANOSTRUCTURING OF SOLID SURFACES BY XUV DISCHARGE-PUMPED XUV LASER SOURCE

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Abstract

The experimental results of interaction of focused XUV laser beam (wavelength 46.9 nm) with Polymethylmethacrylate (PMMA) and GaAs samples will be presented. Proximity-standing golden grid showed on naturally-generated diffraction pattern that direct nanostructuring is possible.

Keywords: **XUV laser, laser ablation, diffraction pattern**

1. INTRODUCTION

The first demonstration of XUV Ne-like argon laser working on 46.9 nm was published in [1]. Rocca's experiment opened a new way to the development of simpler and compact XUV lasers based on excitation pumping by capillary discharge. Generally, the fast capillary discharge apparatus have some advantages in comparison with the other approaches (e.g. with laser created plasma, free electron lasers, generation of high harmonics: capillary discharge experiments are relatively simple in design, compact and cost-effective.

Our research team was inspired by many applications of coherent soft X-ray/XUV radiation and began to build the fast capillary discharge device CAPEX (CAPillary EXperiment) just about seventeen years ago. We designed and assembled the CAPEX device that turned out to be in a good agreement with the numerical simulations [2]. The CAPEX apparatus was modified in 2003, mainly the region of its spark gap and the capillary part [3]. We substituted polyamide capillary by a ceramic (alumina) one. The new capillary material significantly reduced wall ablation. The short (~1.5 ns) intense spike of the soft X-ray signal was detected by a vacuum photodiode. It was proved that this short pulse corresponded to amplified spontaneous emission of neon-like argon line. The time-resolved (~30-50 ns exposition) XUV spectra recorded the strong spectral line, which dominated the whole observed spectrum in the range of 10 – 110 nm [4]. The wavelength of this dominating spectral line was just 46.9 nm. According to our experience with CAPEX the new apparatus CAPEX-U (-Upgrade) [6] was assembled approximately seven years ago [5] with intention to find lasing at shorter wavelength on discharge-pumped installations. For testing and application purposes we built a small Marx generator capable to run in a repetitive regime. Its repeating frequency is currently up to 1 Hz [7].

This work reports on our effort to nanostructure a solid surface by XUV radiation. We used for that a natural-pattern created by single imperfectly-focused XUV laser beam. Coherent XUV radiation for these experiments was provided by capillary-discharge based Ar8+ laser (46.9 nm/~0.8-40.0 mJ/ ~1.2 ns) [3,9]. Polymethylmethacrylate (PMMA) was used as a target for ablation in these experiments. This target material was selected not only because it was used by Chalupsky et al. [10] in his thorough study of ablation for metrological purposes, but also because it is also widely used in electron-beam, EUV/XUV, and x-ray lithography as a photoresist. The first results of the patterning of PMMA by ablation with our discharge-pumped laser system (46.9 nm) were presented in [11].

2. EXPERIMENT

2.1. CAPEX apparatus

As an XUV laser at 46.9 nm the CAPEX device was used. The CAPEX apparatus consists of the Marx generator, the coupling section, the pulse forming line, the main spark gap and the capillary. Experimental setup of the device is shown in the **Fig. 1**.

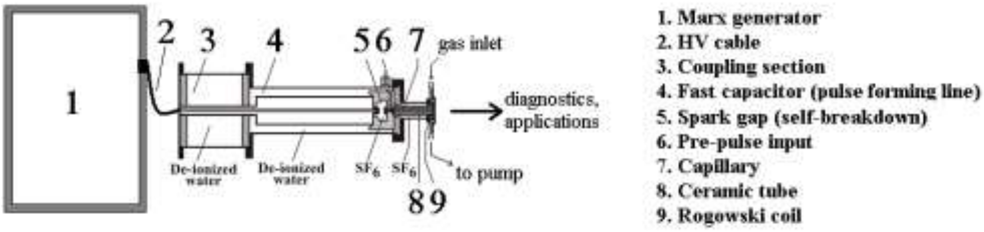

Fig. 1 Schematic drawing of the CAPEX device.

An important component of the CAPEX device is the capillary itself. The 400mm long capillary is directly attached to the spark gap (having one common electrode). At present we use ceramic capillary (3.2 mm in inner diameter). More details about CAPEX apparatus can be found in [7].

For nanostructuring experiments the CAPEX apparatus was extended for vacuum chamber (see **Fig. 2**) with spherical multilayer (14 Sc/Si double-layers of equal geometrical thickness {13.15±0.3} nm) mirror mechanically controlled from atmospheric side by double Cardan joints with Wilson vacuum seals, and interaction tube with mechanically controlled sample. Its standard position was in sagital mirror focus.

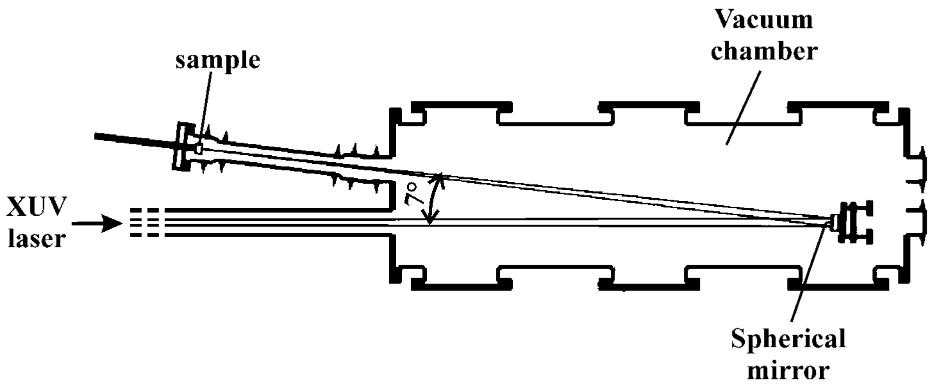

Fig. 2 Experimental arrangement of the irradiation of target.

2.2. Irradiation of PMMA

In our experiment the bare PMMA was ablated through proximity-standing grid (step 12.5 μm x 12.5 μm, window 7.5 μm x 7.5 μm). It turned out that in grid windows near the laser-spot centre the ablated crater is quite smooth extending even to unexposed parts that are hidden under grid´s bars. On the other hand, in windows closer to laser-spot periphery a relief of two-dimensional diffraction pattern starts to appear (see **Fig. 3**). The laser-beam footprint was analyzed by atomic force microscope (AFM). It is worth mentioning that the diffraction pattern engraved in PMMA has been shown also in [8].

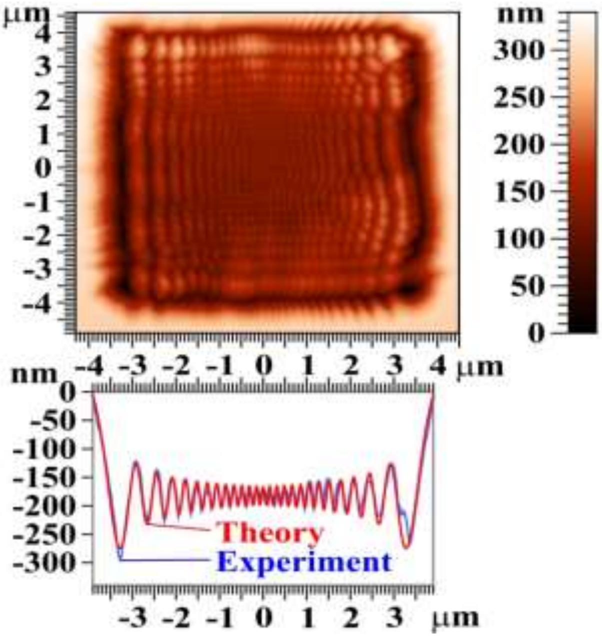

Fig. 3 AFM analysis of diffraction pattern imprinted in PMMA through grid window 7.5x7.5 μm by XUV laser pulse. *Top:* 2D image *Bottom:* The depth profile in the mid of the rectangle.

2.3. Irradiation of GaAs

A different picture is obtained, if the target material is GaAs. The situation repeats even if GaAs is illuminated through proximity-standing grid. In grid windows, were the local radiation dose exceeded desorption limit, but did not reach the ablation threshold the two-dimensional diffraction is imprinted in the GaAs surface (see **Fig. 4**). The relief depth is very shallow amounting ~7 nm, while the depth of analogical diffraction pattern in PMMA was ~250 nm. Irregularity of experimental profile (bottom part of **Fig. 4**) is caused by bent edges of grid-window-sides. Due to that analysis slips from one line of diffraction maxima to intermediate position and further to neighbouring maxima-line.

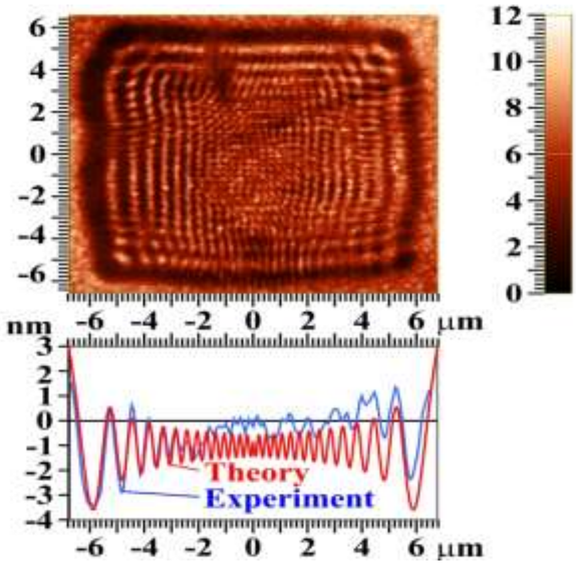

Fig. 4 AFM analysis of diffraction pattern imprinted in GaAs by XUV laser pulse. *Top:* 2D image *Bottom:* The depth profile in the mid of the rectangle. The disagreement of theory and experiment in central and right part of the graph is caused by bent edges of grid-window-sides; due to that analysis slips from one line of diffraction maxima to intermediate position and further to neighbouring maxima-line.

3. CONCLUSION

It was found that interaction of nanosecond pulses of XUV radiation with solid surface strongly depends on substrate material. Illumination of GaAs surface through windows of proximity-standing grid creates in region with desorption process a two-dimensional diffraction pattern, which demonstrates a possibility of direct nanostructuring. Illumination of PMMA surface through windows of proximity-standing grid creates under suitable conditions also a two-dimensional diffraction pattern. It is believed (due to smooth transition between these two regimes not proved) that this nanostrucuring occurs also in the region with desorption regime only.

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