PROCEEDINGS OF SPIE

Damage to VUV, EUV, and X-Ray Optics II

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Editors

21–23 April 2009
Prague, Czech Republic

Sponsored by
SPIE *Europe*

Cooperating Organizations
Institute of Physics, Academy of Sciences (Czech Republic)
Department of X-Ray Lasers, Institute of Physics (Czech Republic)
Czech and Slovak Society for Photonics
Photonics Society of Poland (Poland)

Published by
SPIE

Volume 7361

Proceedings of SPIE, 0277-786X, v. 7361

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:
Author(s), "Title of Paper," in *Damage to VUV, EUV, and X-Ray Optics II*, edited by Libor Juha, Saša Bajt, Ryszard Sobierajski, Proceedings of SPIE Vol. 7361 (SPIE, Bellingham, WA, 2009) Article CID Number.

ISSN 0277-786X
ISBN 9780819476357

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

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Introduction

Damage to VUV, EUV and X-ray Optics II (XDam2) Conference (held every two years in Prague) focuses on studies of damage to optical elements irradiated by high average and/or high peak fluxes of high-energy photons, i.e., VUV/EUV radiation and x-rays. The number of participants is growing, showing that this is a lively and very active research area.

Irreversible changes in various materials induced by high fluxes of EUV/x-ray photons were first studied more than twenty-five years ago (for a review of early studies see [1]). However, it is only in the last decade that this type of research became very active, primarily due to the development of new, intense EUV and x-ray sources.

Systematic studies in this field are driven by different goals and interests:

1) estimating and minimizing damage to surfaces of highly irradiated EUV/x-ray optical elements for the guiding and focusing of short-wavelength laser beams as well as those used for long-term irradiation with high repetition rate sources,
2) durability assessments of materials suggested for the first walls of ICF reactors and optical elements exposed to intense UV/x-ray radiation in a laser-plasma interaction chambers,
3) diffraction-limited ultra-structuring and patterning of solid surfaces for fabrication of microelectronic and micromechanical elements and devices,
4) determination of radiation field characteristics: imaging of spatial radiation energy distribution in a focused beam imprinted on the irradiated material and determination of pulse energy content,
5) production of very dense plasma with low electron temperatures, i.e. kT_e ~ 10 eV, which is often called WDM—Warm Dense Matter.

Although this conference is primarily focused on damage to surfaces of highly irradiated EUV/x-ray optical elements and the effect of long-term irradiation with high repetition rate sources, we believe the results presented here will also be of interest to researchers working in other areas listed above.

The EUV/x-ray sources used for material modification emit at both low peak power (synchrotron radiation and rotating anode sources) and high peak power (free-electron lasers - FELs and various sources based on hot dense plasmas).

The short-wavelength FEL facilities (FLASH [2], LCLS [3], European XFEL, FERMI@Elettra, SCSS, Japanese XFEL) and their optics were introduced and discussed in details in the first part of this conference. These were followed by several contributions about laboratory-scaled sources utilizing collection and focusing of EUV/x-ray radiation emitted from laser-produced plasmas. These sources provide long EUV/x-ray pulses as compared to FEL facilities, are very handy, and their operation is economical. Thus, they represent a work-horse in the rapidly growing area of UV/x-ray-induced nano-structuring and surface modification.

With low-peak-power sources, materials are primarily removed by photo-induced desorption of material components from the irradiated sample surface. Each EUV/x-ray photon carries enough energy to break any chemical bond. This energy is usually also higher than the cohesive energy of any crystal. Therefore the photons absorbed in a near-surface region may create small fragments of a sample material, which are emitted into the vacuum. It is necessary to underline, that in the case of low-peak-intensity irradiation, material is removed only from the surface and a very thin near-surface layer.

The situation is quite different when the sample is exposed to a high-peak-power source that delivers energy in individual, high-energy pulses. The sample is then exposed to a high local dose of radiation (given by the energy content of the pulse and the absorption length of the radiation in the irradiated material) in a short period of time (given by the pulse duration), i.e. at a very high dose rate. This means that a large number of events that cause radiation-induced structural decomposition (i.e., polymer chain scissions, etc.), occurs almost simultaneously in a relatively thick layer of irradiated material. Since a portion of the radiation energy absorbed in the material will be thermalized, the sudden heating of the layer, which is also heavily chemically altered by the radiation, must be taken into account. The overheated, fragmented region of the sample represents a new phase, which tends to blow off into the vacuum. These particular processes, as well as specific features of short-wavelength ablation with respect to ablation induced by conventional UV-Vis-IR sources, represent the subject of interest of numerous research groups.

Results of extensive investigations in both above-mentioned modes have been reported at the conference in various materials (e.g., elemental semiconductors, aluminum foils, molecular solids) and composed systems (e.g., single thin layers deposited on a massive substrate, multilayers, phase zone plates). In addition to that, the intermediate region between the desorption and the ablation was indicated and demonstrated. Experiments with the tightly focused FLASH beam gave a unique chance to observe all three phenomena appearing together on the surface of a crater created by a single FEL shot.

Although most of participants reported desorption and ablation of irradiated material, i.e., photo-induced erosion, several contributions presented at the conference were dealing with an expansion of irradiated material or carbonaceous solids deposition on irradiated surfaces. The surface contamination of EUV/x-ray optics by radiation-induced carbon deposits and protection against the damage of this kind is of interest from scientific and technological perspective [4].

With soon-be-operational x-ray FELs the interest is shifting towards the short-wavelength region (~ keV) and ultra-high intensities (micro-focusing issues). This is also bringing challenges for the theory and computer modeling of radiation damage.

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