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Interaction of VUV-FEL radiation with B4C and SiC at 32nm wavelength

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The output fluence and pulse duration of XFELs such as LCLS and TESLA will pose significant challenges to the optical components which may be damaged by the XFEL beam [1]. It is expected that low-atomic-number materials such as SiC, B_4C, and diamond exhibit weak absorption and therefore are damaged least. It has been suggested that the fundamental damage mechanism that determines the fluence damage threshold for single-shot exposures is thermal melting of the materials [2]. For multiple-shot exposures, the damage threshold is potentially lower than the melt threshold due to fatigue effects associated with mechanical stresses during to thermal cycling [3].

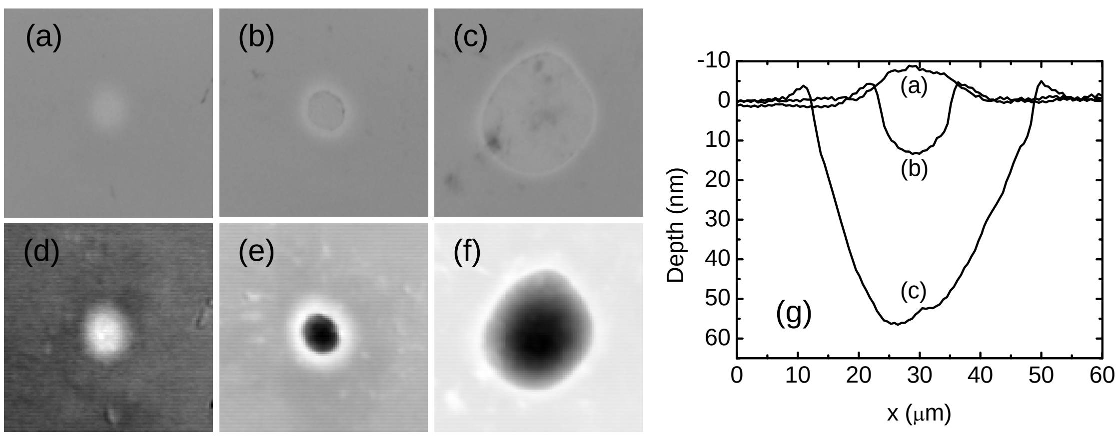

Figure 1: VUV-FEL exposed SiC samples. (a) through (c) show Nomarski DIC micrographs of spots exposed at fluences of less than 0.28 J/cm^2 ((a) and (b)) and 0.72 J/cm^2 (c). Figures (d) through (f) show the corresponding depth profiles. The range of the linear black (depression, positive) to white (extrusion, negative) scale is (d) 4 to -9 nm, (e) 13.5 to -5.5 nm, and 56.5 to -6 nm (f). The width of pictures (a) through (f) is 31.6 μm. Figure (g) shows vertical lineouts through the center of the damaged regions.

We exposed slabs of SiC and B_4C to the VUV-FEL radiation at a wavelength of 32 nm, with a pulse duration of 25 fs, and a fluence of up to 2.54 J/cm^2. (Experiments on SiC and B_4C thin films were inconclusive due to problems with changing coordinate systems that made the identification of exposure sites impossible.) Figures 1 (a) through (c) show representive Nomarski DIC micrographs of areas on a SiC sample exposed at different VUV-FEL fluences. Figures 1 (d) through (f) show the corresponding surface profiles, and Figure 1 (g) shows a lineout through the center. We obtained similar results for B_4C. For low-fluence exposures (less than 0.3 J/cm^2) for which surface modifications were detectable, we observed both craters and extrusions of a few nanometers in height. For larger fluences up to 2.5 J/cm^2, we observed only craters that were tens to hundreds of nanometer deep. From the surface profiles we extracted the peak crater depths. Figure 2 show the peak depth in SiC as a function of VUV-FEL fluence. For extrusions we defined the depth as the negative of the extrusion height. For larger fluences greater than 0.3 J/cm^2, we found that the peak depth generally increases with beam energy. For smaller fluences less than 0.3 J/cm^2, the trend is not as clear. We attribute this observation to the large noise in the pulse energy measurements at low fluence.

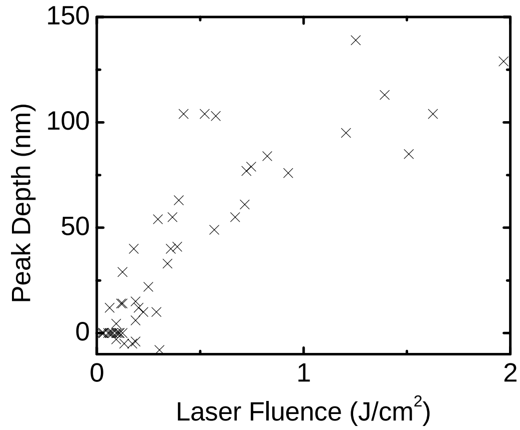

Figure 2: Peak crater depth as a function of nominal laser fluence for SiC bulk samples. Negative depth values refer to surface extrusions. Fluences below 0.3 J/cm^2 are noise-dominated.

The noise problem in the total energy measurement for low fluences prompted us to perform a statistical analysis in order to extract the surface damage threshold. We assume that the low-fluence beam energies follow a similar statistical distribution as the high-fluence beam energies. With this analysis we found that the surface-damage fluence threshold for these ultra-short VUV-FEL pulses (0.13-0.17 J/cm^2 for SiC, 0.18-0.21 J/cm^2 for B_4C) are comparable to the fluences required for thermal melting (0.083 J/cm^2 for SiC, 0.062 J/cm^2 for B_4C). We further found that for larger fluences ($\geq$ 0.3 J/cm^2) the crater depths corresponds to temperatures of 7350 K ± 2990 K and 7120 K ± 2580 K for SiC and B_4C, respectively.

In this round of experiments were not able to study low-fluence multiple-shot effects due to the stochastical variation in the beam energy. Since it was not possible to measure pulse energies at low fluence reliably, we were not able to verify that there were not a few high-energy outliers during the 100-10000 shot exposures. In future experiments it would be extremely useful to have well-calibrated beam-energy measurements at low fluences for single and multiple shots-exposures. This will also allow us to rid ourselves from the statistical analysis referred to above. Further, it will be useful to study exposures at shorter wavelengths in order to be closer to the XFEL regime and in order to maximize the radiation penetration depth. For Si-based materials it is desirable to stay above the Si absorption edge around 12.4 nm.

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[1] A. Wootton, J. Arthur, T. Barbee, R. Bionta, R. London, H.-S. Park, D. Ryutov, E. Spiller, and R. Tatchyn, Proc. SPIE **4500**, 113 (2001).
[2] R.A. London, R.M. Bionta, R.O. Tatchyn, and S. Roesler, Proc. SPIE **4500**, 51 (2001).
[3] D.D. Ryutov, Rev. Sci. Instr. **74**, 3721 (2003).