Studies of ultrafast femtosecond-laser-generated strain fields with coherent x-rays

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Introduction

In its new 324-bunch mode of operation, the Advanced Photon Source (APS) has opened new avenues of femtosecond (fs) laser science and techniques. In this new mode if one uses the tightly focused low pulse energy (nJ) high repetition rate fs-laser Ti:Sapphire oscillator (88 MHz) in hutch 7ID-D, every laser pulse and X-ray bunch can be overlapped and delayed with respect to each other, resulting in a high repetition rate pump-probe experiment that uses all of the APS X-ray bunches. This poster describes how coherent X-ray experiments might be used to study laser-generated strain fields in semiconductors. With an oscillator beam focused to 6 μm onto GaAs, we have observed coherent X-ray diffraction patterns with a high-resolution CCD camera. We have developed two techniques to observe the strain field: a topographic technique and a coherent diffraction technique. The coherent diffraction technique is more spatially sensitive than the topography method and easier to interpret. It will be shown in the poster session. The topographic technique will be discussed in more detail in this report.

Methods and Materials

The beamline 7ID Si (111) monochromator was set to 10 keV and detuned by 50% to reduce the third harmonic contamination. The beam energy bandpass is 0.014%. An X-ray slit placed ~20 cm from the sample could reduce the illumination area to a beam of $3x10^7$ coherent X-rays/s within an area of 7 μm by 7 μm. The Ti:Sapphire oscillator beam has a nominal wavelength of 800 nm, a pulse length of 30 fs, a repetition rate of 88 MHz, and an average power of 0.3 W. It was focused down on a GaAs (111) or (001) sample using a long working distance Mitutoyo objective with X5 magnification. By scanning a knife edge, we observed a focal waist of 5.9-μm FWHM. The diffracted X-rays were absorbed on a YAG:Ce single-crystal screen, generating visible fluorescence at 550 nm, which was imaged using a CoolSNAP HQ CCD camera and a X10 microscope objective [1].

Results

Figure 1 (laser on) and Fig. 2 (laser off) show the diffracted images of the GaAs (111) plane at the peak intensity of the rocking curve. The vertical axis is parallel to the vertical 2θ angle, while the horizontal axis of the image is along the X-ray beam horizontal direction. The vertical direction of the image is a combination of vertical diffraction and the vertical profile of the incident beam. With laser off, the X-ray topograph reveals significant structure, which we believe is caused by native stress from mounting and polishing the thin sample. As seen in Fig.1, the laser destroys the diffraction of GaAs (111), but the effect does not permanently damage the sample. When the laser is switched off, the diffraction reverses back to Fig. 2 within a fraction of a second. The laser power delivered on the sample was 115 mW, which corresponds to 14.5 mJ/cm^2 of pulse energy density. Laser melting and ablation in GaAs occur around 100 mJ/cm^2. Figure 1 is independent of the time delay between the laser and X-ray or the laser pulse width.

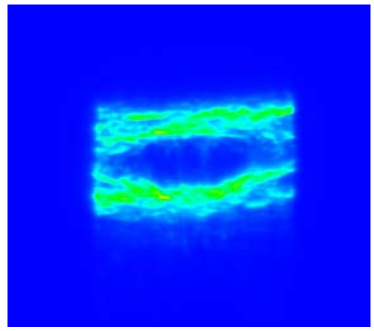

Fig. 1. Laser-on topograph of GaAs (111). The intensity from 0 to 2900 ADU in an exposure time of 70 ms is displayed from blue to red. The hole vertical and horizontal FWHM is 100 and 250 μm, respectively, far greater than the laser spot size.

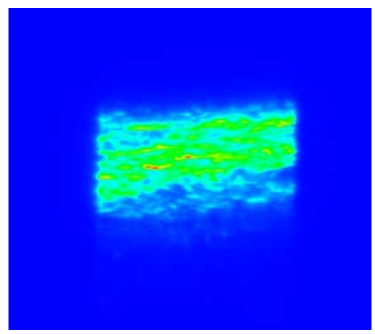

Fig. 2. Laser-off topograph of GaAs (111).

Discussion

Finite element analysis calculations estimate a peak temperature difference of the GaAs (111) of 160K. The laser-induced strain causes a large average diffraction loss, but the topography technique is not very spatially sensitive to the tightly focused laser beam. The topography technique is very useful for the initial alignment of the X-ray beam with the focused laser beam. Future experiments will match the sample thickness to the laser penetration depth in order to limit the X-ray diffraction to the laser-heated volume.

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References

[1] E. M. Dufresne et al. *Proceedings of the SRI2003 Conference*, AIP Conference Proceedings vol. **705**, Melville, New York, p. 780-783 (2004).