INTERFEROMETRY

Watching Ripples on Crystals With a Sagnac Interferometer

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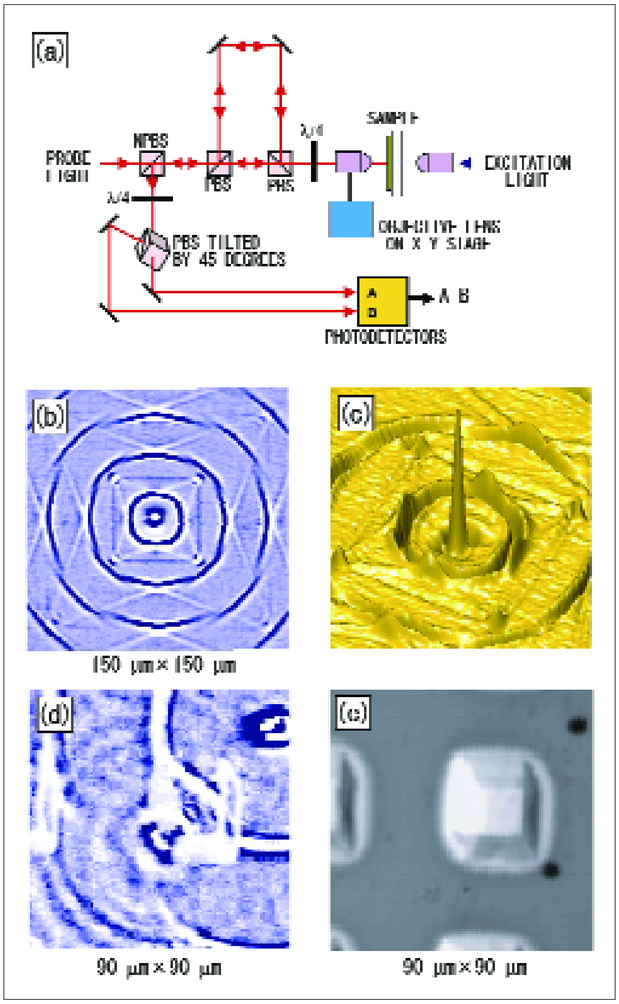
Laser acoustic techniques, because of their non-contact nature, are attractive vehicles for probing the mechanical and elastic properties of solids. Particular sensitivity to near-surface properties or to thin films can be obtained by optically generating and detecting surface acoustic waves (SAW). Although progress in this field has been promising,[1] the signal-to-noise ratio has not been sufficient to allow real-time imaging of SAW focusing patterns in elastically anisotropic materials. With the increasing use of SAW on crystals in applications such as the SAW filters used in communication systems and cellular phones, this is a problem of significant practical importance.



150 μm × 150 μm

90 μm × 90 μm

90 μm × 90 μm

Figure 1. (a) Sagnac interferometer used for surface acoustic wave imaging in real time. PBS, NPBS and λ/4 mean polarizing beam splitter, non-polarizing beam splitter and quarter-wave plate. The probe light enters the interferometer with its plane of polarization at 45° to the plane of the diagram. (b) SAW image for the (001) surface of TeO_2 coated with a 40-nm Au film. (c) 3D rendering of the central portion of (b). (d) and (e): SAW and optical reflectivity images for a crown glass substrate coated with a 140-nm Cr film and Au pyramids. The excitation optical pulses are incident at the top right.

We describe a new method for imaging SAW in real time using an ultrafast optical technique involving a Sagnac interferometer.[2] We image SAW at frequencies of up to 1 GHz generated at a point source in isotropic and anisotropic solids and make animations of their propagation.

The samples used are metallic thin films on transparent substrates [see Fig. 1(a)]. We excite the SAW with a train of blue optical pulses, each of a duration of about one picosecond, arriving at the surface periodically at intervals of about ten nanoseconds. This light is focused through the substrate onto a micrometer-sized spot on the sample, thus stimulating SAW through thermal expansion. After each blue light pulse, we fire two infrared probe pulses onto the front surface of the film. The highly stable Sagnac interferometer[3] is designed to monitor the optical phase difference between these probe pulses and to follow the tiny surface displacement induced by the SAW, typically only 0.2 atomic diameters. By scanning the lateral probe position and probe delay time, SAW wave fronts can be imaged with micrometer spatial and picosecond temporal resolutions.

Figure 1(b) corresponds to a SAW image of a 150 μm × 150 μm region of tellurium oxide, a tetragonal crystal coated with a 40-nm polycrystalline gold film. The pattern is exquisitely intricate owing to the strong elastic anisotropy and shows the expected four-fold symmetry and caustic behavior for the (001) crystal cut used.[2] Figure 1(c) shows a 3D rendering of the central portion of Fig. 1(b).

Figures 1(d) and (e) show, respectively, SAW and optical reflectivity images for a 90 μm × 90 μm region of a microstructure consisting of an array of flat-topped gold pyramids (1-μm-high polycrystalline) deposited on a 140-nm polycrystalline chromium film on a glass substrate. The acoustic refraction clearly visible at the pyramid boundaries, which produces an inversion of the SAW wave-front curvature inside the pyramid, is mainly caused by the difference in SAW propagation velocities in gold (~1 km s^{-1}) and in glass (~3 km s^{-1}).

Direct dynamic optical visualization of SAW wave fronts provides new insights into the elaborate underlying mechanisms for SAW focusing, dispersion, refraction and scattering. There are opportunities for a wide variety of studies on subjects such as the animation of phonon ripples on samples of surface phononic crystals (the acoustic analogue of photonic crystals), phonon waveguides and phonon resonators. Practical applications of this ultrafast optical imaging technique in the nondestructive testing of SAW devices or in thin film thickness monitoring are also expected.

References

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3. D. H. Hurley and O. B. Wright, Opt. Lett. **24**, 1305 (1999).

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