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LASER EXCITATION AND DETECTION OF 1D WEDGE WAVES AND THEIR APPLICATIONS IN SENSORS AND ACTUATORS

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ABSTRACT

Laser-based selective excitation and sensitive detection of one-dimensional (1D) wedge waves propagating along the edge of a solid wedge was achieved. These waves penetrate only about on wavelength deep into the solid and therefore are ideally suited to study modifications of edge tips. The phase velocity and penetration depth of the fundamental wedge wave and of a supersonic pseudo-wedge wave were measured for silicon wedges with a pump-probe laser setup. The fundamental wedge wave is well localized and can be employed to detect coatings or tip truncation by the dispersion effect. Strong stress localization leads to intense vibrational movement that can be used in various sensors and actuators.

Keywords: 1D wedge waves, selective excitation of guided waves, non-destructive evaluation of edges, phase velocity dispersion.

INTRODUCTION

Besides three-dimensional (3D) longitudinal and shear bulk waves and two-dimensional (2D) surfaces acoustic waves (SAWs), one-dimensional (1D) guided wedge waves exist at the apex of a solid wedge. In an anisotropic silicon wedge with an apex angle >45° two such wedge waves were found, namely a strongly localized wedge wave (WW) that propagates with a speed below the Rayleigh velocity and a supersonic leaky pseudo-wedge wave (p-WW) with a velocity above the surface and shear wave. Therefore, this latter wave couples with both the shear wave and the SAW. The strong localization of stress and strain at the edge opens new possibilities for the application of laser ultrasound in nondestructive evaluation (NDE) of solids near the wedge tip. Ideal wedges are non-dispersive since no length scale is defined. Any modification of the tip by truncation (e.g. rounding) or an additional layer (e.g. coating) on a wedge face leads to dispersion of the phase velocity. NDE of isolated cracks is possible with WWs on wedges, similar to NDE with SAW pulses on surfaces. The intense vibrational movement of the wedge apex can be used in sensor and actuator applications.

RESULTS AND CONCLUSIONS

For the selective excitation of WWs an optical angle-tunable transducer has been developed that can be placed near the wedge tip (Lomonosov 2012). Laser-probe-beam deflection was used to measure the surface velocity as a function of the distance from the pump location directly at the tip and also perpendicular to the tip yielding the decay of the probe signal at the selected wedge face. This latter measurement probes the localization of the guided wave at the wedge tip and therefore is very important for any applications based on this property. In Fig.1 the typical behavior observed for a localized and leaky wedge mode in silicon are illustrated.

Dispersion-free WWs were measured for several selected wedge configurations of single-crystal silicon. As an example, the results for a wedge consisting of two Si(111) planes and a wedge angle of 70.5° are presented here. The velocity of the localized WW along the wedge was 4.2 km/s and that of the supersonic p-WW was 5.4 km/s. The latter velocity is above the SAW velocity of 4.54 km/s and the shear velocity of 4.67 km/s. Since the velocity of the WW can be obtained quite precisely the dispersion effect allows the accurate determination of wedge distortions such as an additional layer or modification of the tip. For example, the dispersion effect can be employed to monitor the adsorption of water molecules on wedge faces in a humidity sensor.

Another interesting application will be non-destructive testing of isolated surface-breaking cracks on various edged materials such as cutting tools or turbine blades. Similar to the case of NDE with SAWs here the reflection and transmission of WWs takes place at the crack, and in addition, mode conversion to surface and bulk modes may occur. These features make the localization and the characterization of isolated defects on a wedge tip possible.

Furthermore, the strong localization of stress and strain is a characteristic feature of WWs. Accordingly, large vibrational amplitudes can be achieved for these 1D guided waves. This particular feature may find specific applications in actuator devices, e.g., in fluidics. Another interesting point is the efficiency of the induced movement in an ultrasonic motor. In a WW-based device it is provided by resonant oscillations, which may be much stronger than the mechanical vibrations driven by a piezoelectric actuator in a conventional ultrasonic motor.

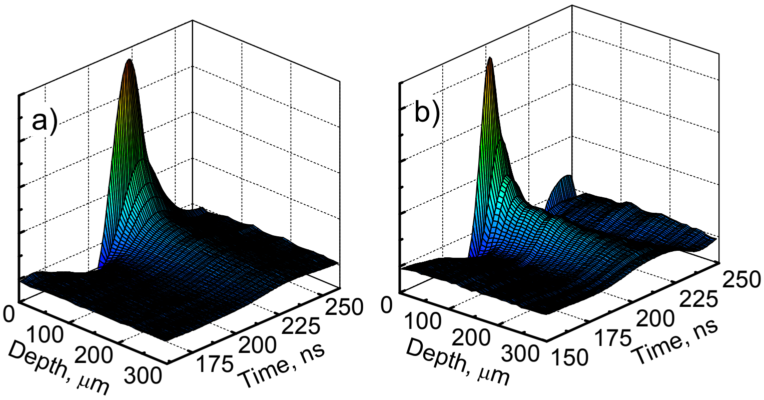

Fig. 1 - a) Measured depth dependence of the fundamental WW in the geometry Si(111)70.5°Si(111).
b) Measured depth dependence of the p-WW leaking into the SAW for this configuration.

In conclusion, WWs provide a novel tool for NDE, sensor, and actuator applications. These 1D waves guided by the wedge apex open new possibilities to analyze edged samples. Besides linear also nonlinear WWs may soon play an important role in science and technology, e.g., as solitary waves (Mayer 2009).

REFERENCES

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