Measurements of Surface-wave Harmonic Generation in Nonpiezoelectric Materials*

D.C. Hurley

Materials Reliability Division, National Institute of Standards & Technology, Boulder, CO 80303

Abstract: Methods to excite surface waves suitable for harmonic-generation experiments in nonpiezoelectric materials have been investigated. Of the methods evaluated, combs appeared to offer the greatest potential. Results are presented here for narrowband waves (center frequency ~10 MHz) generated by a comb and detected with a path-stabilized Michelson interferometer. Out-of-plane displacements as large as 32 ± 1 nm were measured. The spatial behavior of the fundamental and second-harmonic components indicated that diffraction effects were significant.

INTRODUCTION

Use of Rayleigh waves to investigate higher-order elastic properties of surfaces promises to provide valuable information for materials characterization, but remains largely unexplored. Moreover, experimental work in this area lags far behind development of corresponding theoretical models. One experimental technique for examining nonlinear surface-wave effects is the use of narrowband waves to perform harmonic-generation experiments. This approach allows knowledge of the relationships between harmonic generation and bulk elastic properties [1] to be exploited, and therefore has been chosen for the current work.

Progress in surface-wave harmonic-generation experiments is hindered by lack of suitable excitation means. Desired characteristics of source waves include relatively large displacement amplitudes and low harmonic distortion. Several methods for exciting narrowband Rayleigh waves exist, but each has its drawbacks. For instance, an interdigital transducer is a popular device for this purpose. However, it requires a piezoelectric substrate and hence is severely limited in its application to materials characterization. A wedge can also be used to convert longitudinal waves into Rayleigh waves. Unfortunately, spurious harmonic components can be generated in the wedge itself, thus obscuring effects in the specimen.

Another, although less well-known, possibility is the Sokolinskii comb [2]. This device consists of a plate with alternating "teeth" and grooves. The tooth spacing corresponds to the Rayleigh wavelength in the specimen. A transducer is attached to the comb's flat side; the other (tooth) side is bonded to the specimen. Transducer excitation results in creation of a surface wave in the specimen.

Experiments were performed to compare Rayleigh waves generated by a wedge, an electromagnetic acoustic transducer, a longitudinal transducer placed on a corner at 45°, and a comb. Comparison of the detected signals in the time and frequency domains indicated that the comb attained the best compromise between large displacement amplitude and high spectral purity. In this paper, initial results using a comb are reported.

EXPERIMENTAL APPARATUS

The experiments used a single-crystal LiNbO₃ transducer and a thin aluminum comb of the same diameter (6.35 mm). The comb contained 21 grooves, nominally spaced 300 μm apart and 100 μm deep. Toneburst electronics (17 cycles at 9.85 MHz, approximately 600 V peak-to-peak) were used to excite the transducer. Wave displacements normal to the surface were measured using a path-stabilized Michelson interferometer (laser wavelength λ=1064 nm). Measurement techniques were similar to those used previously for bulk experiments [3], except that the excitation source and the laser probe beam were on the same side of the specimen. The laser beam was focused onto the specimen, obtaining a spatial resolution of approximately 20 μm. The specimen was mounted on motorized translation stages so that the position of the probe beam relative to the (fixed) comb could be varied.

The detected waveforms were digitally processed using frequency-notch filters to obtain the out-of-plane amplitudes $A_1$ and $A_2$ of the fundamental and second-harmonic displacement components, respectively.
RESULTS AND DISCUSSION

Data obtained with the apparatus described above are depicted in Fig. 1. The figure gives the measured values of $A_1$ and $A_2$ for Rayleigh waves propagating on the surface of a 25-mm-thick plate of 6061 aluminum. The measurements were made along the comb axis (that is, perpendicular to the long direction of the teeth) and are plotted versus distance $x$ from the comb center. The figure shows that the comb excited Rayleigh waves with out-of-plane displacements greater than 25 nm; for instance, $A_1=32 \pm 1$ nm for $x=24 \pm 2$ mm. Moreover, Fig. 1(b) reveals that these amplitudes were sufficiently large to produce measurable second-harmonic components. This in itself is significant: it was unknown if any method would prove suitable in practice on nonpiezoelectric materials. Figure 1 also shows that $A_1$ decreased rapidly with distance, indicating that diffraction effects were considerable. Increasing the transducer diameter would lessen the effects, but they cannot be eliminated for a practical-sized device. In spite of the decrease in $A_1$, $A_2$ was observed to grow with distance in these experiments.

Results of a nonlinear Rayleigh-wave theory incorporating diffraction [4] were compared to the experimental data. For the fundamental component, excellent agreement between experiment and theory for a uniform source (dashed line in Fig. 1a) was obtained using a source velocity amplitude $v_0=3.5$ m/s (source out-of-plane displacement $A_{10}=24$ nm) and a Rayleigh distance $x_0=68$ mm. Small discrepancies between predicted and observed values may be attributed to slight deviations in the transverse position away from the true on-axis position. The predicted spatial evolution of $A_2$ is indicated by the dashed line in Fig. 1b. It can be seen that agreement between theory and experiment is excellent if the value $\beta_{11}=0.1$ is used to characterize the specimen's second- and third-order elastic properties. In other aluminum alloys with known second- and third-order elastic moduli [5], values for $\beta_{11}$ are higher (0.15–0.45) but roughly the same magnitude. Future plans include further experiments to better understand comb behavior, and refinement of a theoretical model for comb transduction. Nonetheless, these results demonstrate the potential of combs for nonlinear ultrasonic surface-wave experiments.

REFERENCES

* Contribution of MST, an agency of the US government; not subject to copyright.