A LASER PROBING SYSTEM FOR CHARACTERIZATION OF SAW PROPAGATION ON $LiNbO_3$, $LiTaO_3$, AND QUARTZ

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ABSTRACT

A nondestructive high-resolution technique for the optical detection of the phase and amplitude of high-frequency surface acoustic wave (SAW) devices is presented. The test setup incorporates a mode-locked ps-laser, harmonic mixing, and coherent detection. Dynamic range and minimum detectable surface displacement were 50 dB and 1 $pm/\sqrt{Hz}$, respectively. The probing technique allows not only the measurement of the SAW field but also the precise direct determination of the phase velocity which is a fundamental design parameter in SAW technology. We present experimental results of the phase velocity of both SAW and Leaky SAW modes on quartz, $LiNbO_3$ and $LiTaO_3$ with an accuracy of up to $1.5 \cdot 10^{-5}$. Our results agree very good with theory and other experiments.

INTRODUCTION

SAW devices are used in a considerable and increasing range of applications in modern microwave systems to carry out particular signal processing functions with great technical facility. Their advantage over concurrent techniques are their small size and cost-effective mass-production combined with high performance. The major technical applications are momentarily both front end- and IF-filtering in mobile radio transceivers and (both fixed-code and programmable) matched-filtering in spread-spectrum systems. Modern software tools for the design of such high-performance SAW devices are based upon the knowledge of the anisotropic phase velocity $v(\Phi)$ of SAW's propagating in piezoelectric substrate materials such as $LiNbO_3$ (lithiumniobate), $LiTaO_3$ (lithiumtantalate) and quartz. Since frequency stability is a pertinent issue in the design of a SAW device, the phase velocity should be known with an accuracy as high as possible in dependence of the crystal cut, propagation direction, temperature and frequency. In what follows, we present a nondestructive laser probing technique which allows for the precise direct measurement of the SAW phase velocity as well as for the field distribution measurement of a SAW device while in operation. Our method is based on the phase-preserved optical detection of the field of a given SAW wavetype.

MEASUREMENT SYSTEM

For the optical detection technique we have adopted the method of balanced photodiodes [1] which enables the phase-sensitive imaging up to 2 GHz limited by the diameter of the laser beam focused on the surface of the device under test (DUT) (Fig.1). The surface displacement due to the propagating SAW mode changes the angle of the reflected laser beam. The deviation in angle which is typically in the 10^{-5}rad range is detected as the differential output of a pair of photodi-

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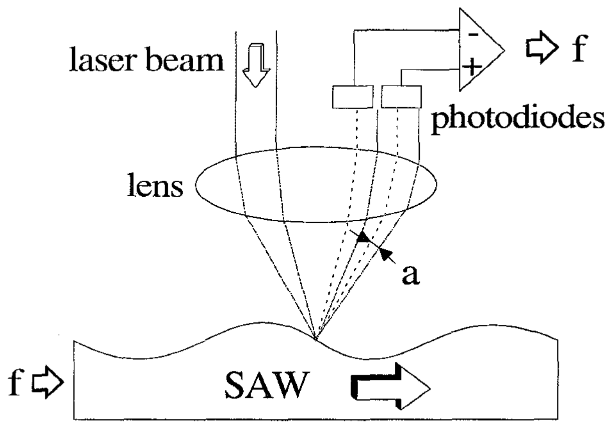

Fig. 1: Balanced photodiodes.

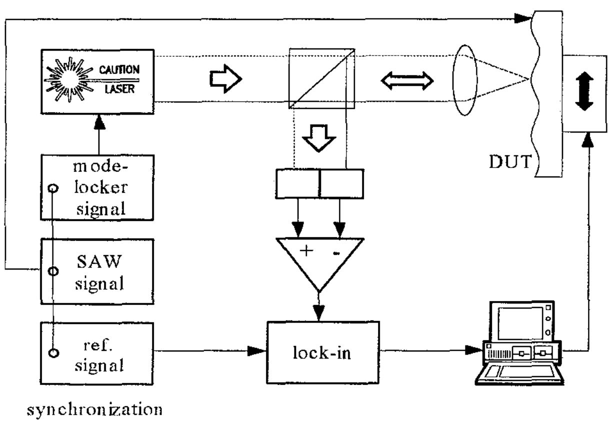

Fig. 2: Test setup schematic.

odes. As a light source, we use a mode-locked pulsed Nd:YAG laser system. The laser provides a harmonic mixing spectrum containing the complete information about the SAW at a low frequency component which can be processed in a signal chain [2] [3]. The test setup incorporates three synthesizers for signal generation, synchronization, and mode-locking, and a lock-in amplifier for detection (Fig.2).

DATA PROCESSING

The direct determination of the phase velocity results from scanning the laser beam along the direction of the propagating SAW (x-direction) and sampling the local phases and amplitudes. The phase-preserved imaging requires a local resolution of less than half of the wavelength. The higher the scan path and thus the higher the number of test points, the higher the accuracy. Using scan lengths of up to 40 mm at a number of 40000 test points, we attain relative accuracies of up to $1.5 \cdot 10^{-5}$.

For the processing of the measurement data we use two methods operating respectively in the time domain (TD-method) and the frequency domain (FD-method). The TD-method is in particular useful when analyzing harmonic SAW waveforms. Note, that the test points do not represent a time dependence but a local dependence of phase and amplitude. For an efficient averaging, we fit the sine function to the test points. A function $A + Bsin(2\pi x/\lambda + \phi)$ is composed of the parameters A, B and ϕ, and also of the wavelength λ which is searched for. A simplex algorithmus minimizes the distances between the test points and the sine function at the x positions by optimizing the parameters A, B, ϕ and λ. Then the phase velocity v can be derived from the relation $v = \lambda f$ with f being the signal frequency known with an accuracy of better than 10^{-7}. The advantages of the TD-method are to attain highest accuracy for a given number of test points and to make visible the distribution of the phase velocity along the SAW propagation path. However, the method has its shortcomings if the detected signal has an arbitrary non-harmonic waveform. Therefore, an FD-method, i.e. an analysis of the measurement data in the frequency domain using FFT, is applied to provide additional information of the wave propagation.

RESULTS

Our measurement setup allows for the experimental determination of the slowness of a given piezoelectric wafer. The slowness is defined as the inverse of the angle-dependent phase velocity $v(\Phi)$ and describes the anisotropic behavior of a piezoelectric crystal. The direct measurement of the slowness curve requires on principle for launching SAW's at the full angular range of 0 to 360°. To fulfill this demand, 3-inch test wafers were fabricated incorporating 16 transducers in a central-symmetric arrangement, and the angle dependence of the phase velocity was measured in steps of $\Delta\Phi = 22.5^o$. The experimental results for 128°-YX-$LiNbO_3$ (measured at 230 MHz and 25°C) are shown in Fig.3. A simplex algorithm was used for the data fit. Please note, that one measurement campaign (which may consist of the recording of more than 32000 test points) provides simultaneously the phase velocity v and the power flow angle γ. The power flow angle gives the angular deviation between the wave vector and the propagation direction (i.e. the wave propagates in a direction that is not normal to the wavefronts) which occurs in an anisotropic medium (beam steering effect). The accuracy of our measurement is ± 0.1 m/s for the phase velocity and $\pm 0.1^o$ for the power flow angle. Our slowness results agree very good with published results [4],[5].

Measurement results for ST-quartz and 36°-YX-$LiTaO_3$ using FFT analysis are given in Fig. 4. Each of the graphs shows characteristic peaks corresponding to a certain wavetype. Since the distance between two subsequent test points (step size) is 1 μm, we have a Nyquist wavelength of 2 μm (corresponding to the Nyquist frequency). That means that the closer a peak is to the zero of the abscissa ("spatial zero point"), the higher is the wavelength and thus the phase velocity. The particular peak occuring at the spatial zero point is the Fourier transform of a small offset generated in the lock-in amplifier. ST-quartz has one characteristic peak in the Fourier spectrum, a fact which indicates pure Rayleigh wave operation. The phase velocity derived from the maximum peak was determined to be 3149 m/s. Measurements on 128°-YX-$LiNbO_3$ produced nearly the same spectrum which also indicates a Rayleigh wave mode. In this case the phase velocity was 3973 m/s.

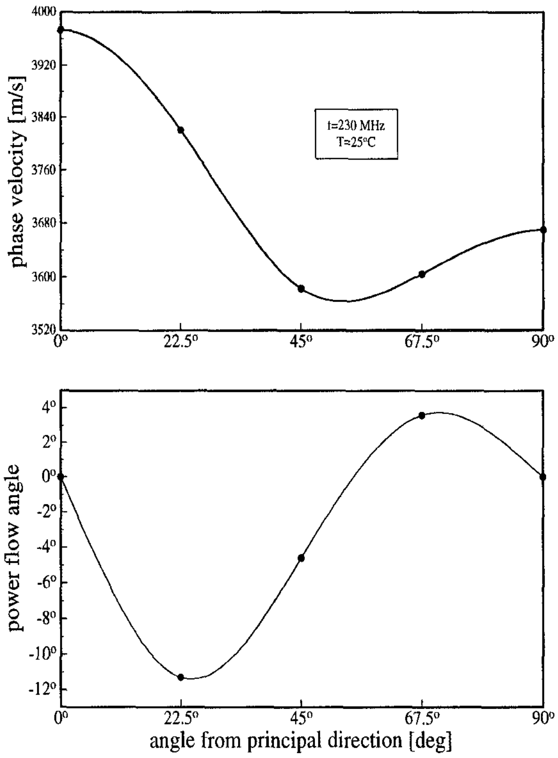

Fig. 3: Slowness data.

The crystal cut 36°-YX-$LiTaO_3$ exhibits a special Fourier spectrum with two distinct peaks (Fig.4). The peak closer to the zero point results from the LSAW mode (LSAW: leaky surface acoustic wave), the other peak from the traditional SAW mode (Rayleigh wave). The existence of the LSAW mode on $LiTaO_3$ allows $LiTaO_3$ to be a very good compromise between quartz- and $LiNbO_3$-cuts both from the device efficiency and the temperature stability point of view. E.g., 36°-YX-$LiTaO_3$ is the major substrate for mobile radio RF filters. LSAW devices on $LiTaO_3$ are completely or partially (mostly in the form of strip gratings) metallized, a fact which however has no important impact on our measurement technique which also enables the probing of metallized surfaces. Another difference between SAW modes and LSAW modes is due to their different polarizations. Whereas the SAW is elliptically polarized in its sagittal plane showing a high normal field com-

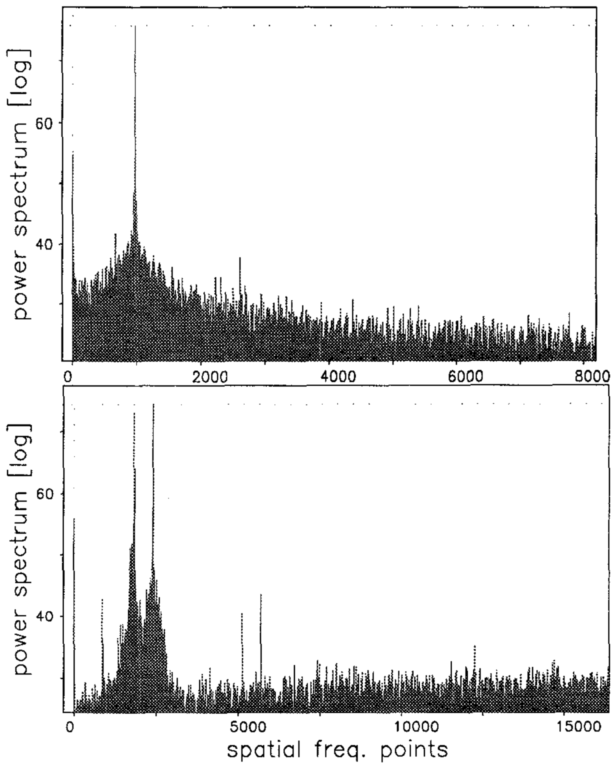

Fig. 4: Spectra of SAW on ST-quartz (top), LSAW and SAW on 36°-YX-$LiTaO_3$ (bottom).

ponent, the LSAW is mainly horizontally polarized with only a small normal component. Thus, the surface displacement which is mainly evaluated by an optical probing technique (see Fig.1) is (at a given signal energy) much smaller with a LSAW than is the case with a SAW. However, since the minimum detectable surface displacement and the dynamic range of our test setup are respectively 1 $pm/\sqrt{Hz}$ and 50 dB, also LSAW modes can easily be measured. The Rayleigh mode is excited simultaneously on 36°-YX-$LiTaO_3$ when the LSAW mode is launched from an interdigital transducer. The power of the Rayleigh wave is much smaller than that of the LSAW on this particular crystal cut, but due to the fact that mainly the normal field component is evaluated by the prober, the high peaks shown in Fig.4 arise. We investigated both the cases of free and completely metallized surfaces, and our results, which are given in

LSAW		Rayleigh wave	
free	metallized	free	metallized
4263	4099	3124	3122

Tab. 1: Phase velocities on 36°-YX-$LiTaO_3$ [m/s].

Tab.1, were in good agreement with theoretical calculations [6].

CONCLUSION

The present measurement method system is a very useful nondestructive evaluation tool for SAW technology. In comparison to the group velocity measurement technique of test chips, much more precise phase velocity data is obtained. Moreover, the phase-preserved detection scheme used in our probing technique allows not only to directly determine the phase velocity but also to measure the field distribution in an arbitrary part of the SAW device in operation.

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