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OPTICAL INVESTIGATION OF THE 50 MHz SURFACE ACOUSTIC WAVE (SAW) FIELD1)

K. ČÁPOVÁ2), I. ČÁP3), Žilina

Experimental verification of an optical method for phase sensitive detection of SAW is presented. It is based on the deflection of a focused laser beam by the SAW relief. The focusing lens is used to convert the angular deflection to a lateral shift of a collimated beam which is then detected by a double-section photodiode and a differential amplifier. The lock-in technique is used for the phase sensitivity. The equipment was tested to probe the amplitude, phase and standing-wave ratio of the SAW up to 50 MHz.

ОПТИЧЕСКОЕ ИССЛЕДОВАНИЕ ПОЛЯ ПОВЕРХНОСТНЫХ АКУСТИЗЕСКИХ ВОЛН С ЧАСТОТОЙ 50 МГц

В работе представлены результаты экспериментальной проверки оптического метода детекции поверхностных акустических волн, который чувствителен к изменению фазы. Этот метод основан на отклонении сфокусированного лазерного луча рельефом поверхностных акустических волн. Для преобразования углового отклонения коллимационного пучка в поперечный сдвиг, который детектировался при помощи двухсекционного фотодиода и дифференциального усилителя, использовались фокусирующие линзы. Для определения фазовой чувствительности был применен метод синхронизации. Проведены испытания аппаратуры с целью исследования амплитуды и фазы, поверхностных акустических волн, а также коэффициента стоячих волн вплоть до частоты 50 МГц.

I. INTRODUCTION

The optical methods of investigation of the surface acoustic waves (SAW) have been discussed by many authors. The principle of all discussed methods consists either the diffraction of the laser beam caused by the SAW [1], [2] or the deviation of the focused laser beam reflected by the sample surface with SAW, e.g. [3]. Both mentioned principles were realized in different ways. One of them, using

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1) Contribution presented at the 9th Conference of Ultrasonic Methods in Žilina, August 23—25, 1984.

2) Dept. of Theor. Electrotechnics and Electrical Engines, Univ. of Transport and Communications, 010 88 ŽILINA, Czechoslovakia.

3) Dept. of Physics, University of Transport and Communications, 010 88 ŽILINA, Czechoslovakia.

a double-section photodiode for detection of the laser beam deviation caused by SAW, was published by Engan [4] for a very high frequency region. The simplified modification of that method for radio-frequencies was described by Čápová and an improved modification by Čápová and Čáp [6]. The last method has been experimentally tested up to its frequency limit and the results are presented in this paper.

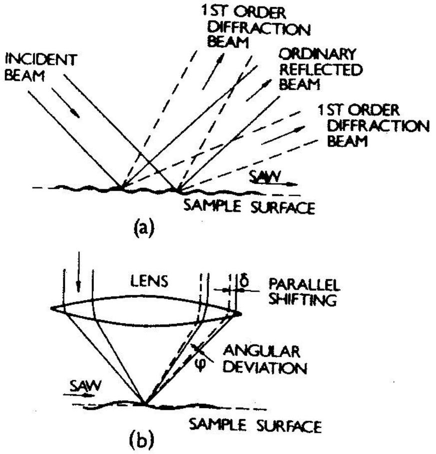

Fig. 1. Reflection of the laser beam on the SAW sample surface (a) diffraction of the unfocused beam; (b) deviation of the focused beam.

II. THEORY

The sample surface with SAW represents the periodic structure from which the laser beam is reflected. In case of the diameter of a laser beam at the sample surface being much larger than the SAW wave length, light difraction of the periodic structure will occur, Fig. 1 (a). If the diameter of the focused laser beam is less than the SAW wave length, we can observe the usual light reflection at the sample surface. The ripples of the sample surface due to the SAW cause the reflected light beam angle deviation and after recollimation the parallel shifting of the laser beam comes into existence, Fig. 1 (b).

The experimental arrangement using the focused laser beam deviation is given in Fig. 2. The recollimated laser beam shifting is detected by a double-section photodiode with a differential amplifier, Fig. 2 (b). The difference signal is then processed by the electronic system to become either the amplitude or the phase information about the probed SAW at the reflecting point.

To get the required information the SAW was generated by means of an interdigital transducer (IDT) supplied by the modulated rf signal with only a single side modulation band. The SAW dependence can be given by the relation

$$y = a_1 \cos[(\omega + \Omega)t - Kx + \varphi_1] + a_2 \cos[(\omega + \Omega)t + Kx + \varphi_2] \qquad (1)$$

where y is the sample surface deviation due to SAW, a_1 and a_2 are the direct and reflexted SAW amplitudes, ω is the rf angular frequency, Ω the modulation angular frequency, K the SAW wave number, φ_1 and φ_2 are phase constants.

The reflected beam angle deviation is proportional to the sample surface gradient, so that the differential amplifier output signal is

$$u_D \sim I_0 R\ \{a_1 \sin[(\omega + \Omega)t - Kx + \varphi_1] - a_2 \sin[(\omega + \Omega)t + Kx + \varphi_2]\},$$

where I_0 is the incident laser beam intensity, R the sample surface reflectivity at the reflecting point.

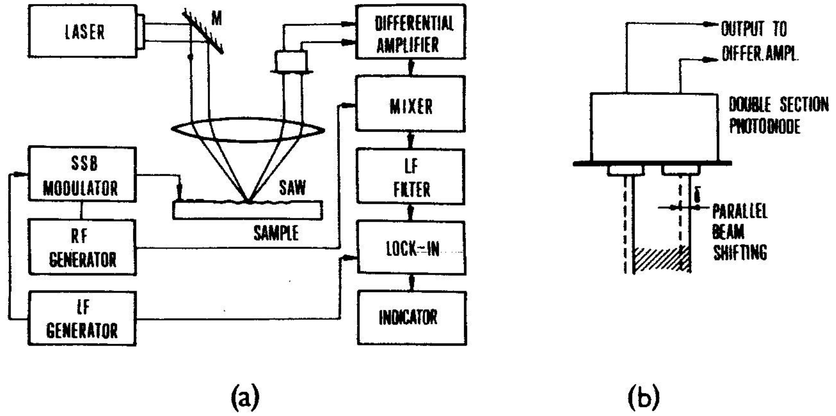

Fig. 2. The experimental arrangement.

After mixing with the reference signal of the rf generator the low frequency signal is obtained

$$u_L = kI_0R\ [a_1 \sin(\Omega t + Kx + \varphi_1) - a_2 \sin(\Omega t + Kx + \varphi_2)] \qquad (3)$$

where u_L is the output voltage of the low frequency amplifier, k is the constant given by properties of the corresponding part of the electronic device.

The voltage (3) can be expressed as a time harmonic function

$$u_L = A \sin(\Omega t + \alpha) \qquad (4)$$

where the amplitude A is given by

$$A = kI_0R\ [a_1^2 + a_2^2 - 2a_1a_2 \cos(2Kx - \varphi_1 + \varphi_2)]^{1/2} \qquad (5)$$

and the phase

$$\alpha = -\operatorname{arctg} \frac{a_1 \sin (Kx - \varphi_1) + a_2 \sin (Kx + \varphi_2)}{a_1 \cos (Kx - \varphi_1) - a_2 \cos (Kx + \varphi_2)} . \tag{6}$$

It is seen that the amplitude of the low frequency output signal changes periodically between two extreme values

$$A_{max} = kI_0R\ (a_1 + a_2) \tag{7}$$

$$A_{min} = kI_0R\ |a_1 - a_2| \tag{8}$$

due to the motion of the focused laser beam spot along the SAW propagation direction. The ratio of both values determines directly the standing-wave ratio at the reflecting point.

III. EXPERIMENT

The described method of SAW probing was experimentally tested by means of the set-up shown in Fig. 2. LiNbO$_3$ samples with evaporated interdigital transducers for generating the SAW and surface strip structures were used. The electronic device components had the following parameters: A He-Ne laser power of about 3 mW, a tunable rf generator 10—500 MHz, a low frequency generator of 1 kHz.

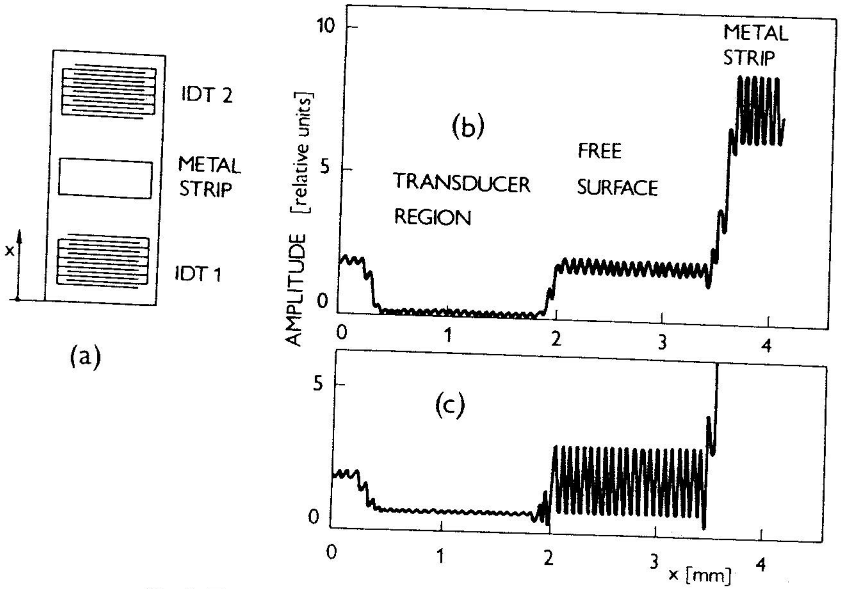

Fig. 3. The LF signal amplitude measurement at 25 MHz [6]
(a) the investigated device, (b), (c) the obtained dependences of the amplitude on the laser beam position along the SAW propagation direction.

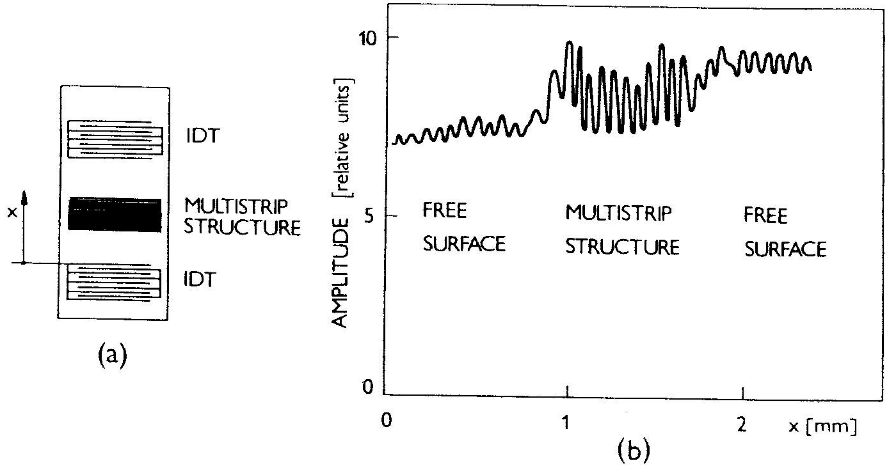

Fig. 4. The LF signal amplitude measurement at 50 MHz
(a) the investigated device; (b) the obtained dependence of the amplitude on the laser beam position along the SAW propagation direction.

The generated SAW power was 10 mW, which corresponded approximately to a 10^{-10} m SAW amplitude. The SAW device was placed in a holder with a micrometric shifting for scanning the sample surface by the focused laser beam.

The surface structure represented by Fig. 3 (a) was used in the first experiment at 25 MHz. The partially standing SAW was generated by IDT 1 feeding only, Fig. 3 (b). The low frequency signal amplitude was measured along the SAW propagation direction by moving of the laser beam. We can see, Fig. 3 (b), that in the region of IDT 1 the standing wave existed, but in the other part of the sample the SWR approached to unity. The step between the free surface and the metallized surface region is due to different surface reflexivities. Another situation is seen in Fig. 3 (c), where both IDT 1 and IDT 2 were fed by the same signal. The superposition of both waves gave a partially standing wave between both transducers but in the transducer region the travelling SAW existed.

The other samples with similar results were proved at the frequencies of 25 MHz and 15 MHz. For the investigation of the frequency range of the described method we arranged an experiment at 50 MHz with the PIN double section photodiode which had a cut-off frequency of 100 MHz. A surface structure with multistrip coupler was used, Fig. 4 (a). The plot of the low frequency signal amplitude along the SAW propagation direction is given by Fig. 4 (b). The SAW propagated along the free surface was a travelling wave conversely to the multistrip structure where the SWR rose a little because of its resonant structure character. From maximum distances we can obtain the SAW wave-length $\lambda = 69\ \mu$m and the corresponding SAW velocity $v = 3450$ ms^{-1}.

IV. CONCLUSION

The described experiments verified the theoretical conclusions of the suggested method. The main fact is that the method is suitable for obtaining the complete amplitude and phase information on the SAW field at the sample surface in the frequency range of the photodetector. The method is much simpler as regards experiments than the methods based on the diffraction pattern analysis. The double-section photodiode light processing leads to a considerable increase of the signal-to-noise ratio and a reduction of sensitivity to vibrations. The method could be suitable for testing and designing of planar microelectronic or electroacoustic and optoacoustic devices.

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