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Feasible study on electro-ultrasonic spectroscopy of silicon single crystal

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1. Introduction

Various nondestructive methods have been developed in order to evaluate electronic components for the quality assurance of electronic equipment. Nonlinear effects as well as linear ultrasonic techniques has beeen implemented for evaluation of electric componenets.

Recently a new method so-called electro ultrasonic spectrospcopy (EUS), which measures intermodulation voltages due to the electric and ultrasonic excitations, has been developed. The ultrasound in a conducting structure can affect the resistance of the sample under test. Resistance of sample may be varied by the change of contact area of conducting grains in the sample. Defects and inhomogenieties in the sample are also the source of intermodulation.

Since the voltage measured for the given sample depends on the current through the sample and on the resistance induced by the ultrasound, the measured intermodulation voltage for the sample, U_m is given by

$$U_m = I_M \Delta R_M \sin\omega_E t \sin\omega_U t\,, \qquad (1)$$

where I_M is the magnitude of electric current, ΔR_M is magnitude of resistance change due to intermodulation, $\omega_E = 2\pi f_E$ and $\omega_U = 2\pi f_U$ are angular frequency of electric and ultrasonic excitation, respectively.

Intermodulation frequencies, f_m is given by

$$f_m = f_E + f_U \quad \text{or} \quad f_m = f_E - f_U\,,$$

and the intermodulation signal can be easily separated from the exciting signals. This is a key idea of high sensitivity of EUS.

EUS is a new technique to measure interaction between mechanical and electical properties, so that it may be useful to study electric pars. EUS has been applied to evaluation of micro crcks in conducting materials[1] and thick film resistors[2]. Single crystals of silicon and cadmium telluride were also investigated by EUS[3]. Sinle crystals may have anisotropic properties, and EUS results will be dependent on the orientation of crystal axes. However the crystal orientation was not considered in the previous work.

In the present work, the axes orientation of single crystal has been considered during preparation of sample. Feasibility of EUS on the single crystal study was investigated.

2. Experimental setup

2.1 Specimen

A Si single crystal of 2.75 x 3.00 x 33.0 mm was employed as a specimen. 3 inches diameter and 3 mm thickness of p-type silicon-boron wafer in [100] direction was sliced by using a low speed diamond wheel saw, so that the direction of length is [110] direction. The resistivity of the wafer was 14.4 Ω-cm. Electrodes for 4-point probe were provided on the specimen. Distance between probing electrodes was 20 mm.

2.2 Equipment setup

The block diagram of the EUS measurement is shown in Fig. 1. Ultrasonic signal was generated and amplified. Ultrasonic vibration of test sample was excited by an ultrasonic actuator. Electric excitation was supplied by function generator and potential drop was measured by p-point probe technique. Lowpass filter and low noise amplifier were employed to acquire intermodulated signal.

RF waveforms of intermodulation signal were captured by using A/D converter and frequency components were obtained by using FFT algorithm. Magnitudes of intermodulation signal were determined from the peaks of FFT results.

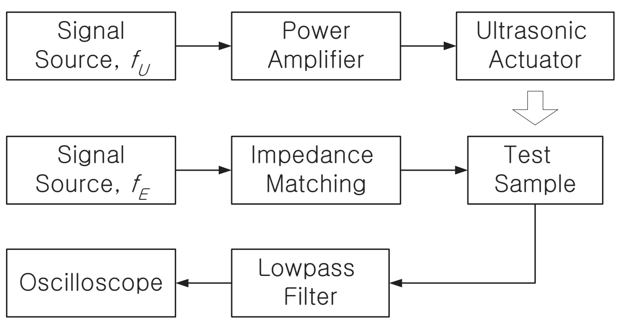

Fig. 1 Schematic diagram of EUS measuring system.

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3. Results and discussion

In order to obtain maximum intermodulation signal ultrasonic excitation frequency was changed and electric excitation frequency determined by separating from ultrasonic one, so that intermodulation frequency is the range of 1 kHz. Typical frequency spectrum of intermodulation signal is shown in Fig. 2. The frequencies of electric and ultrasonic excitation was 33.4 and 31.9 kHz and magnitudes of both excitations was 10 V. The peak of intermodulation signal at 1.5 kHz (marked as '1.H') was clearly observed. In addtion higher harmonics marked as '2.H' and '3.H' were also clearly observed in Fig. 1 which did not appear in the results for the other types of samples used in the previous works. The origin of strong harmonics may be nonlinearity of the sample, however it should be clarified though the extended research.

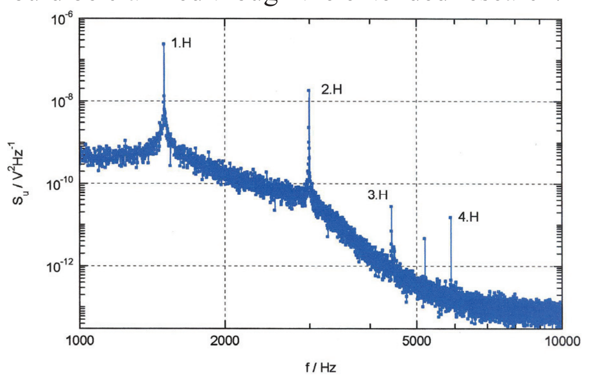

Fig. 2 Typical frequency spectrum of intermodulation signal. f_E = 33.4 kHz and f_U = 31.9 kHz.

The amplitudes of intermodulation signal were determined from the frequency spectrum by using

$$U_m = \sqrt{S_U \Delta f}\,, \qquad (2)$$

where S_U is the value of the frequency spectrum density and Δf is the frequency resulution [3].

Fig. 3 shows the intermodulation voltage obtained during changing amplitude of electric excitation. As the amplitude of electric excitation increased, intermodulated signal increased, however it was saturated for large amplitude (>7 V) of electric excitation. It seems to be caused by large resistance of the sample.

Fig. 4 shows the intermodulation voltage obtained during changing amplitude of ultrasonic excitation. As the amplitude of electric excitation increased, intermodulated signal increased. Ths slop of linear curve fitting was m = 2.6 which is different from the result of previous work [3]. It was expected that m = 1 because modulation amplitude will be linearly proportional to the change of resistance by ultrasonic excitation as given in eq. (1). Therefore it is concluded that there is nonlinear effect in the resistance change due to ultrasonic excitation.

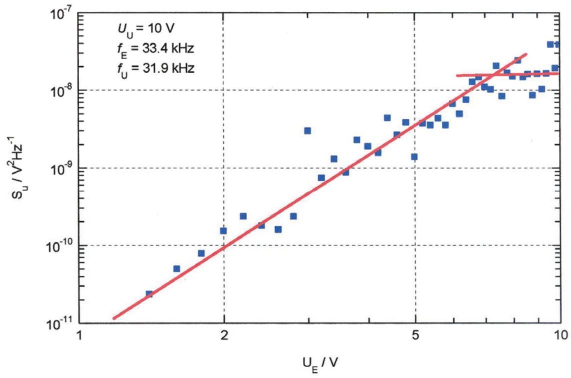

Fig. 3 Intermodulation voltage versus amplitude of electric signal for 10 V ultrasonic excitation.

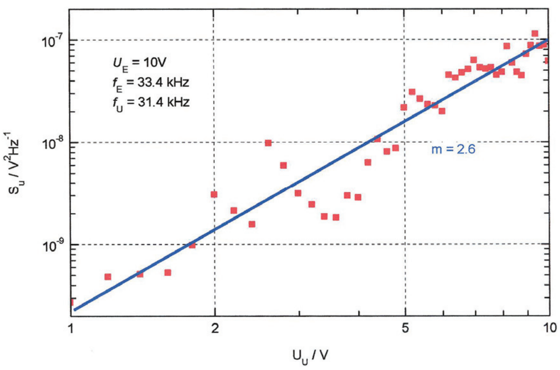

Fig. 4 Intermodulation voltage versus amplitude of ultrasonic signal for 10 V electric excitation.

Conclusions

Feasibility of EUS on the single crystal study was investigated. It was found that strong higher harmonics of intermoulation appears and slope in modulation amplitude versus excitation signal is quite differesnt from those in previous works. They imply that the nonlinear effects are involved in intermodulation of electric and ultrasonic field for a [110] silicon single crystal.

Acknowledgment

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References

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