PRESSURE SENSITIVITY OF RAYLEIGH AND SEZAWA WAVE IN ZnO/Si(001) STRUCTURES

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Abstract

In this study we investigate the pressure effect on the guided waves in ZnO/Si(001) structures. Our experimental results reveal a strong dependence of the pressure sensitivities on the depth penetration of waves. This dependence is explained by studying the effect of layer thickness and wavelength on the pressure sensitivity of Sezawa and Rayleigh waves. The measured results show that strain compensation can be achieved in ZnO/Si structure. Theoretical result obtained by considering strain effect in Silicon substrate alone are compared with measurements and show a good agreement in the case of Sezawa wave. Concerning the Rayleigh wave, the ZnO film effect should be taken in consideration in theoretical formulation.

Introduction

Various studies were performed on the sensitivities of surface acoustic wave in piezoelectric substrate to different physical quantities such as force, pressure and temperature [1], [2]. The applied pressure induces static stresses and strains in the crystal, which by nonlinear coupling modify the wave velocity or frequency. It is necessary to minimize these effects in the case of devices like oscillators since they are at the origin of most of the frequency instabilities. Nevertheless high sensitivities can be used also for sensor applications. To generate elastic waves, interdigital transducers (IDTs) have been developed by classical photolithographic process on a piezoelectric layer deposited on a silicon substrate. Zinc oxide (ZnO) was chosen as the thin film layer to excite the elastic wave.
A perturbation procedure is developed to evaluate the relative frequency shift versus applied pressure by taking into account only the strain effect in the silicon substrate. This assumption is used for Sezawa mode for which the pricipally part of the wave will travel in the substrate.

In this paper, we present the influence of the pressure on the guided waves in ZnO/Si SAW device. Sezawa and Rayleigh wave's sensitivities are studied in terms of wavelength and film thickness. Experimental results will be presented and compared with theoretical results.

Experimental set-up

Piezoelectric film deposition

Piezoelectric ZnO thin films were deposited by a DC planar magnetron sputtering system on silicon Si (100) substrates. The Zinc target (purity 99.99%) diameter was 4 inch (107 mm) and 6.35 mm thick. Deposition parameters, summarized in table I, were optimized to obtain ZnO films with c-axis orientation. The film thickness was measured with a surface profilometer (Dektak ST^3) and Scanning Electron Microscopy (SEM) on cross section to determine the deposition rate. The crystallographic properties of these films were analyzed by X-Ray Diffraction (XRD) using the Cu Kα radiation. All ZnO films used in this study exhibit a highly c-axis orientation.

Table I: Deposition conditions of Zinc Oxide by DC planar magnetron sputtering.

Ultimate vacuum	<5.10^{-7} mbarr
Target	99.99% Zn – Ø 4inches
DC power	120W
%Ar in Ar/O_2 mixture	30 to 70 %.
O_2 flow	30sscm
Pressure	2.10^{-3} to 2.10^{-2} mbarr
Substrate to target distance	80mm
Deposition rate	56nm/min

SAW delay line fabrication

Aluminum IDT, with uniform finger spacing and metallization ratio of 50%, were deposited by conventional contact UV photolithography on ZnO/Silicon structures. The spatial periods (λ), the number of IDT pair fingers, the inter-IDT distance, and the IDT aperture were respectively fixed at 32 μm or 16 μm, 50, 5mm and 3mm for all devices. The center frequency *(f_0)* of the SAW devices is determined by the phase velocity (*Vp*) of ZnO/Si structure and the wavelength *(λ)*:

$$f_0 = V_p/\lambda \qquad (1)$$

Measurement method

The experimental set-up for pressure characterization is based on a pressure chamber with a ZnO/Si window (Fig. 1). The IDTs deposited on the ZnO/Si SAW device are placed on the surface which is out of the chamber. That window acts as a membrane and plays the role of the propagation medium for surface acoustic waves. The range of pressure investigated is from 20 mbar to 4 bars. To permit reliable and better precision measurements, the pressure variation is controlled by a regulation system.

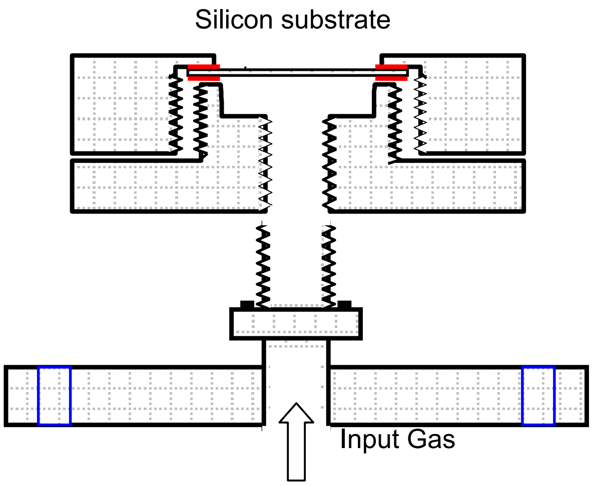

Figure 1: *Schematic diagram of the system used for pressure characterization*

The SAW device is used as a delay line. Data are obtained through measurements made on a network analyser HP 8752A. The frequency variation versus the applied pressure is determined for a fixed phase value.

Experimental Results discussion

In this section, we will discuss the influence of the stress induced by the applied pressure on the surface acoustic wave on a ZnO/Si structures. Both Rayleigh and Sezawa modes are investigated.

Figure 2 shows the relative frequency change of the Rayleigh mode (mode 0) according to the pressure with various layer thickness. Two behaviors depending on normalized thickness value kh (kh=2π(h/wavelength) are observed in figure 2. For kh<<1 the slope of the curve is negative and the absolute value decreases when increasing kh. For kh>>1, the slope becomes positive and keeps almost the same value.

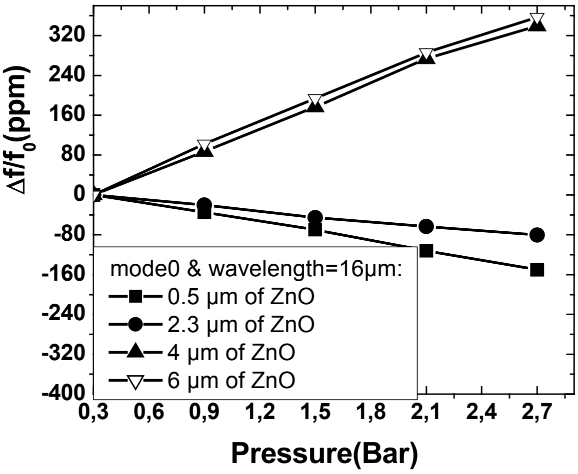

Figure 2: *Relative frequency shift (mode 0) vs pressure for different ZnO thickness*

Figure. 3 show the relative frequency shift versus applied pressure with various ZnO thickness for Sezawa mode (mode 1). Obviously, the sensitivity is higher for smaller ZnO thickness and is found to be linear with the applied pressure.

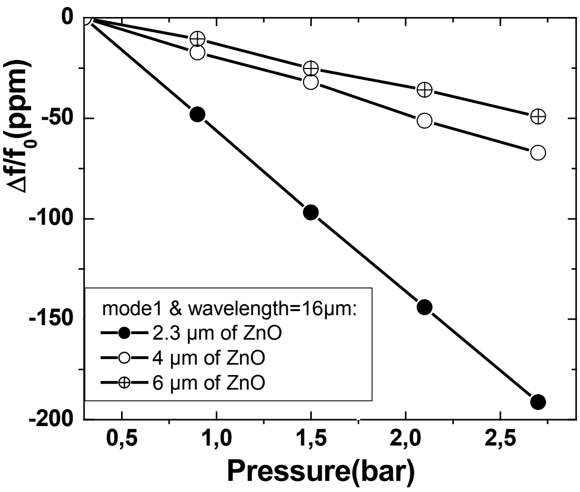

Figure 3: *relative frequency change(mode 1) vs pressure for different ZnO thickness*

Due to the dispersion curves [3], we have chosen a normalized thickness with a kh=0.9 so that the mode 0 and the mode 1 are excited simultaneously. It is well possible to carry out comparisons between the sensitivity of these two modes. We note in Figure 4 that the mode 1 is more sensitive than the mode 0.

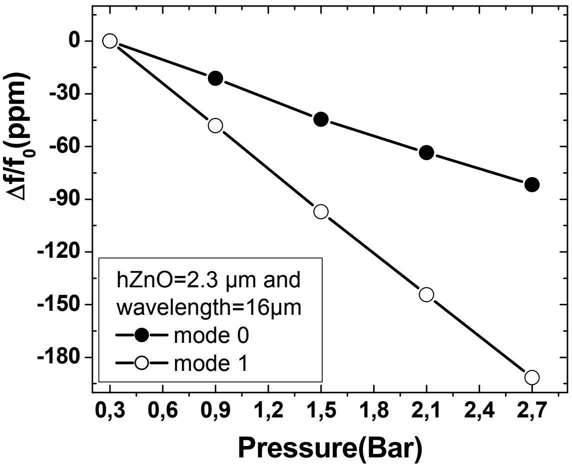

Figure 4: C*omparison of the pressure sensitivity of mode1 and mode 0.*

Another point approached in this study is the effect of the wavelength on the sensitivity. For the same ZnO thickness (6μm), we investigate the sensitivity of mode 1 for different wavelengths λ=16μm and λ=32μm. We found that the sensitivity is improved for the highest wavelength (Fig. 5).

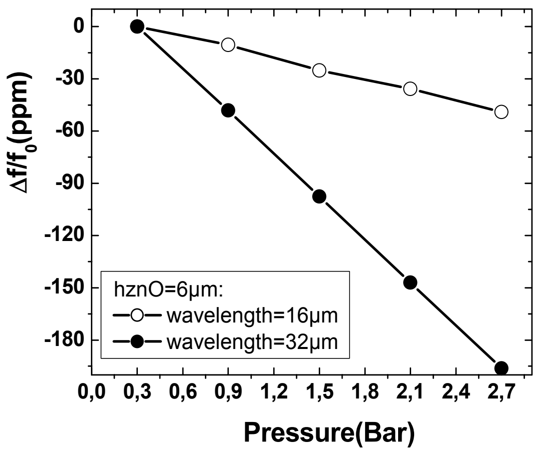

Figure 5: C*omparison of the pressure sensitivity of mode1 for two wavelengths.*

Our preceding results point out that the normalized frequency shift according to the pressure depends on the penetration depth of the wave.
In order to understand how this parameter acts on the pressure sensitivity for the two guided waves, we have displayed for each study the dependance of the particle displacements with respect to the depth direction. Figures 6, 7, 8 and 9 show that by increasing the kh value, the depth penetration of the wave in silicon substrate decreases when those in ZnO increase. This mean that the pressure sensitivity depend on the wave propagation medium. The same dependence between pressure sensitivities and normalized thickness of ZnO was observed in ZnO/Quartz structure also [4].

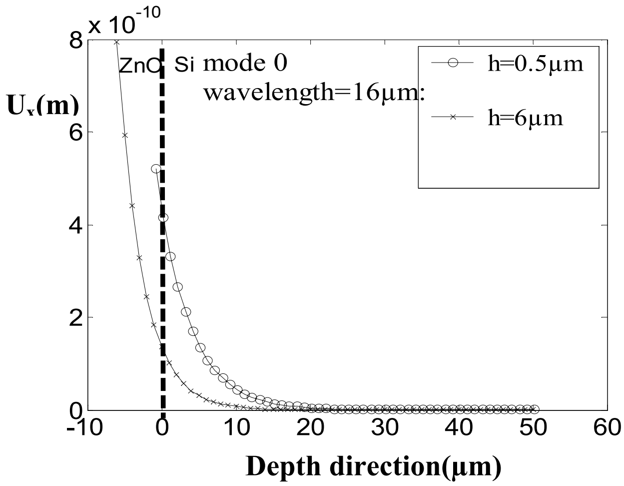

Figure 6: *Dependence of particle displacement with respect to the penetration depth into the ZnO deposited film on Si(100) for mode 0*

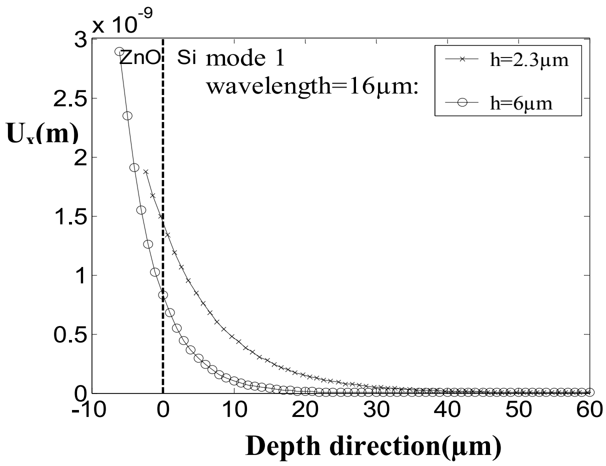

Figure 7: *Dependence of particle displacement with respect to the penetration depth into the ZnO deposited film on Si (100) for mode 1.*

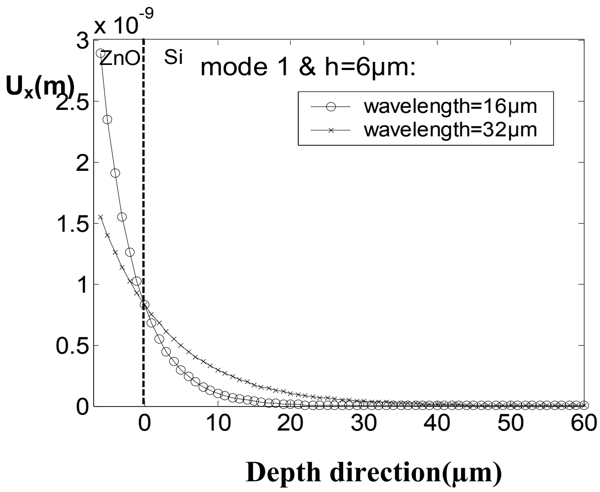

Figure 8: *Dependence of particle displacement with respect to the penetration depth into the ZnO deposited film on Si(100) for mode 1and two wavelengths.*

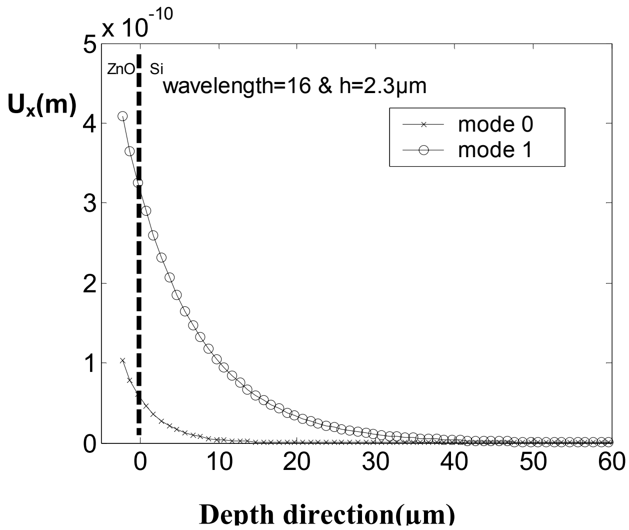

Figure 9: *Dependence of particle displacement with respect to the penetration depth into the ZnO deposited film on Si (100) for mode 1 and mode 0.*

The temperature compensation for different modes observed on multilayer structures should be obtained by the addition of layer with an opposite TCF value. This idea is extended to the pressure effect and experimentaly confirmed by the study of the penetration depth in ZnO and Si Figure 2, 3. These experimental results involve that the Si and ZnO contribution to pressure sensitivity is going in the opposite direction.

We have applied the perturbation method [5] for mode 1 and for the normalized thickness value of 1.15. Due to the fact that mode 1 is affected principally by the silicon properties at this normalized thickness value, the approximation taken into account only strain effect in th silicon can be used. A comparison of the theoritical results and experimental results is carried out and a good agrement is obtained table II.

Table II: Comparison of theoretical and experimental results obtained for mode 1

Normalized thickness kh	1.15 (6μm,λ=32μm)	1.15 (3μm,λ=16μm)
Theoretical results	Δf=-34 kHz f_0=161 MHz	Δf=-68 kHz f_0=322MHz
Experimental results	Δf=-32 kHz f_0=166MHz	Δf=-66 kHz f_0=328MHz

Conclusion

Pressure sensitivities of rayleigh and Sezawa waves in ZnO/Si structure was investigated. We have show that the pressure sensitivity depend on normalized thickness of ZnO. The opposite contribution of Si and ZnO to pressure sensitivity was also confirmed experimentally. A theoretical calculation performed to predict pressure sensitivity of Sezawa wave (mode 1) show a good agreement with experimental results.

Acknowledgements

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