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Tilted c-axis Thin-Film Bulk Wave Resonant Pressure Sensors with Improved Sensitivity

E. Anderås, I. Katardjiev, V. Yantchev

Abstract—Aluminum nitride thin film bulk wave resonant pressure sensors employing c- and tilted c-axis texture, have been fabricated and tested for their pressure sensitivities. The c-axis tilted FBAR pressure sensors demonstrate substantially higher pressure sensitivity compared to its c-axis oriented counterpart. More specifically the thickness plate quasi-shear resonance has demonstrated the highest pressure sensitivity while further being able to preserve its performance in liquid environment.

Index Terms—AlN, micro-acoustic, pressure sensor, sensitivity.

I. INTRODUCTION

ACOUSTIC waves in thin film plates are expected to exhibit high pressure sensitivity due to the plate large aspect ratio [1]. Further, acoustic resonators exhibit low noise performance which in turn provides the possibility to achieve high measurement resolutions. So far, the S0-Lamb wave resonators have shown the highest pressure sensitivity as compared to other plate modes in c-textured Aluminum Nitride (AlN) membranes [2]. On the other hand the influence of the thin film texture on the pressure sensitivity of other acoustic modes has not been assessed so far.

Fig. 1 Cross section of the fixture for pressure measurements

Here the pressure sensitivities of the thickness longitudinal and the thickness shear modes in the thin film bulk acoustic resonators (FBAR) are experimentally studied in a comparative manner. To this end FBARs with both c-textured and c-tilted AlN thin films, respectively have been studied. It

is noted that FBARs are chosen as test devices here because of their excellent properties regarding gravimetric and pressure sensitivity [1, 3] as well as the one dimensional nature of the vibration mode, which in turn allows straightforward interpretation of the pressure sensitivity.

II. EXPERIMENT

FBARs were fabricated employing both c-textured films as well as films with a 26 degrees tilt of the c-axis and a thickness of about 2 μm . Membrane thicknesses as well as c-axis tilts were determined by means of high resolution scanning electron microscope and XRD respectively. The lateral dimensions of the fabricated membranes were 600x600 μm while the active areas, within which the acoustic waves are excited, were 300x300 μm . This specific configuration, where membrane is somewhat larger than the FBAR, was chosen to promote evenly distributed deformation and stress levels within the active device. Thus the FBAR pressure sensitivity defined as the pressure induced fractional change in resonance frequency $S=\delta f/f$ can be approximated by $S=\delta V/V - \delta d/d$, where the first term is the fractional change in velocity V due to the pressure dependence of the elastic constants, while the last term is the plate thickness (d) deformation. Note that the fractional change in velocity is usually dominating the pressure sensitivity. Both quantities are dependent by the pressure induced stress levels in the membrane. For brevity further details on thin film synthesis and FBAR micromachining are omitted since they have been thoroughly described elsewhere [4].

A specially designed fixture was used to measure the pressure sensitivity of the FBARs (Fig. 1). Each FBAR chip is mounted into the fixture by firmly pressing it against an o-ring lubricated with vacuum grease. A digital pressure indicator GE Druck DPI 705 was used to monitor the pressure, while FBAR frequency response was measured by a G-S-G pico-probe supported HP8364B network analyzer. The resonance frequency was identified by the maximum slope of the admittance phase ϕ . The resolution of the pressure indicator in the measured pressure range 0 – 80kPa is 10Pa while the frequency noise empirically estimated over 10 measurements of the resonance frequency [5] is found $3\sigma=0.5\text{ppm}$. The FBAR relative frequency shift due to an applied pressure differential was measured with a pico-probe equipped HP8364B network analyzer. Both the longitudinal and the shear wave fundamental resonances have been measured.

III. RESULTS

Fig. 2 shows the typical frequency responses of two FBARs with a c-textured and a c-tilted thin film respectively at zero pressure differential. A cross section of the measured FBAR topology is also shown in Fig. 2.

Fig. 2, The frequency responses of two FBARs with a c-oriented and a c-tilted film respectively. The insert shows a cross section of the measured FBAR topology.

The FBAR with the tilted c-axis film exhibits two fundamental resonances, namely the shear and the longitudinal at frequencies of about 1GHz and 1.8GHz, respectively. In contrast the c-textured AlN FBAR exhibits one resonance only, the fundamental longitudinal, at frequency a of about 1.8 GHz. It is further noted that a very weak shear response is also present here due to the non-perfect c-orientation of the c-textured AlN film [4].

Fig. 3. FBAR pressure sensitivity

In Fig. 3 the fractional pressure sensitivity of the fundamental resonances in c-textured and c-tilted AlN films are shown as a function of the negative mean stress (internal pressure) induced at the plate center as a result of the applied ambient pressure differential. This specific representation is chosen to eliminate both the frequency scaling and the effect

of crystal anisotropy on the induced stress. It is noted that the major contribution to the pressure sensitivity is due to the stress induced changes in the crystal elasticity [2] thus the results in Fig. 3 show the pressure sensitivity as function of the induced stress levels in the membranes independently of their texture and thickness variations. Here large deformation finite element analysis (COMSOL Metaphysics) was performed to deduce the internal pressure at the membrane center of the membrane under external ambient pressure.

Tilted c-axis AlN FBARs, operating at the fundamental quasi-shear resonance, demonstrates the highest sensitivity as compared to all other acoustic modes. More specifically, a 6 fold increase in pressure sensitivity is demonstrated as compared to that of the longitudinal mode in c-textured AlN FBARs. It is also noted that the significant increase in pressure sensitivity is also manifested when comparing directly the frequency shifts of the FBAR resonances as a function of the applied ambient pressure differential. Thus the results from Fig. 3 indicate that the improvement is to a large extent due to the increased pressure dependence of the shear elastic constant in tilted-c AlN films. The observed phenomenon was verified through a series of pressure measurements.

In addition, the FBARs have been measured in contact with water by dispensing a droplet on the membrane backside. Only the highly sensitive shear resonance preserves its performance in water. Its quality factor Q decreased from about 440 to about 130.

IV. CONCLUSIONS

C-axis tilted quasi-shear mode FBAR pressure sensors demonstrate 6 times higher pressure sensitivity compared to its c-axis oriented counterpart. The findings suggest that the shear FBARs are attractive for pressure micro-sensors operating both in air and in liquid environments. Further, its small dimensions and ability to operate in liquid makes it a promising candidate for in-vivo pressure measurement applications

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