High Power Durable Nano Resonators with Epitaxial Aluminum Electrodes

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Highly textured aluminum films have been grown on mono-crystalline lithiumtantalate ($LiTaO_3$) using ultra thin titanium films as adhesion layers for pure aluminum. Texture measurements by means of EBSD (Electron Backscatter Diffraction) show that the thickness of the intermediate titanium layer significantly influences texture and grain structure of the overlying 400nm aluminum film. Increasing the thickness of the titanium layer from 0 nm to 20 nm leads to a change of aluminums texture from unoriented polycrystalline over highly oriented in single direction to highly oriented in twin structure.

Highly textured or epitaxial thin aluminum films on piezoelectric single-crystalline substrates like $LiTaO_3$ have attracted much interest due to their high stress durability at ultra high frequencies since these films improve the performance of surface acoustic wave (SAW) devices significantly [1]. On a blank $LiTaO_3$ substrate aluminum forms a polycrystalline film with random crystal orientations. To overcome this problem an ultra thin adhesion layer of pure titanium has been used allowing aluminum to grow with a smooth surface and highly textured with crystal axis <111> parallel to the sample normal. Electron Backscatter Diffraction (EBSD) technique supported by Atomic Force Microscopy (AFM) has been applied to obtain information about films microstructure. In our experiment we have found that the surface roughness can be minimized while the collective alignment of grains in one single direction is maximized, if an optimized thickness of the titanium underlayer is chosen.

Starting with a piezoelectric substrate ($LiTaO_3$, 42° Y-X-Cut) six samples have been prepared by deposition of an ultra thin titanium adhesion layer (0, 1, 2, 5, 10, 20 nm) followed by the main metallization comprising of 400 nm pure aluminum. Sequential deposition of titanium and aluminum has been performed by electron beam evaporation in an ultra-high-vacuum environment.

Results of EBSD and AFM analysis are shown in Fig. 1 to Fig. 3. AFM images (Fig. 1-3b) show the surface topography of the samples and the determined average surface roughness (Ra). Different grey scales in the EBSD maps (Fig. 1-3a) indicate different out of plane grain orientations, while white-colored grains represent grains in the major crystal orientation. The pole plots (Fig. 1-3c) show the in-plane textures and the inverse pole plots (Fig. 1-3d) show the out-of-plane textures of the aluminum films.

The first two samples (without titanium and with 1 nm titanium) in Fig. 1 show polycrystalline growth of aluminum with random in-plane orientations (see grain maps and pole plots). AFM measurements demonstrate rough surfaces (Ra > 25 nm).

In contrast, samples with 2 nm and 5 nm titanium adhesion layer show very smooth surfaces (Ra < 3 nm), as depicted in Fig. 2b, and a highly oriented crystal growth with a strong <111> out-of-plane texture, as shown in the inverse pole plot in Fig. 2d. The triple of dark spots in the pole plot (Fig. 2c) indicates one single in-plane orientation, what motivates us to call these films quasi-epitaxial.

The samples formed with 10 nm and 20 nm titanium (Fig. 3) show a strong growth of <111> Al as well. These samples exhibit the same main crystal orientation as the samples with 2 nm and 5 nm, but the aluminum films tend to develop a second in-plane orientation, that is rotated 180° round the samples normal relative to the main crystal orientation, as revealed by the pole plot. The black areas in the EBSD map (Fig. 3a) illustrate these 180° rotated grains.

Fig. 4 shows the orientation of the aluminum lattice on the monocrystalline substrate from the topview, which has been reconstructed from EBSD data. To confirm the crystal direction of aluminum, found by our EBSD measurements, we fabricated SAW devices. We applied heavy load and visualized the degradation of the electrodes by means of scanning electron microscopy (SEM), as shown in Fig. 5. The SEM measurements indicate triangular grains sunk in the electrode fingers due to material migration of aluminum. The grains show the same crystal direction which is revealed by EBSD.

Our results show that titanium as an intermediate layer can strongly enhances the <111> out-of-plane texture of the overlying aluminum film. These results agree well to the results of other work groups [1, 2].

The appearance of a second in-plane Al texture (see Fig. 3) can be explained if one takes into account that titanium develops its own <0001> texture as its layer thickness is increased [2]. With its hexagonal atomic arrangement towards the surface <0001> titanium offers two energetically equal states for the growth of <111> aluminum, which are rotated by 180° compared to each other, as shown in Fig. 6. This atomic arrangement might explain the appearance of Al twin-grains as thickness of the titanium adhesion layer is increased.

References:

[1] O. Nakagawara, "High power durable SAW antenna duplexers for W-CDMA with epitaxially grown aluminum electrodes," 2002 IEEE Ultrasonics Symposium, Proc. (2002), 43.

[2] A. Kamijo, "A highly oriented Al[111] texture developed on ultrathin metal underlayers," J. Appl. Phys. Vol. 77, No. 8, 1995.

Figures:

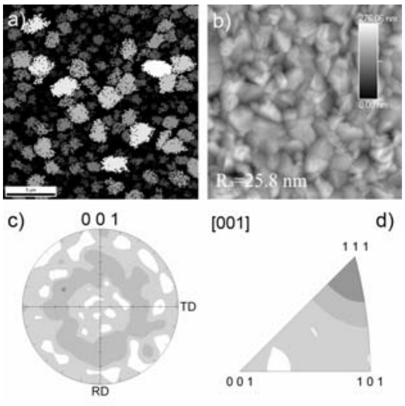

Fig. 1. Grain stucture and texture of 400 nm Al with **0 nm or 1 nm titanium** underlayer

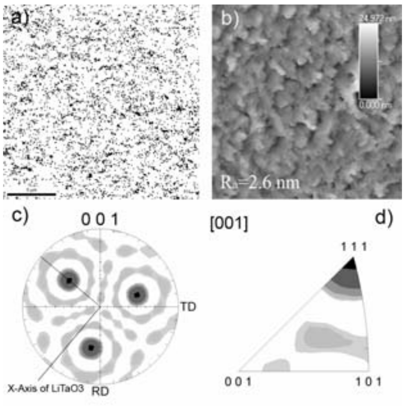

Fig. 2. Grain stucture and texture of 400 nm Al with **2 nm or 5 nm titanium** underlayer

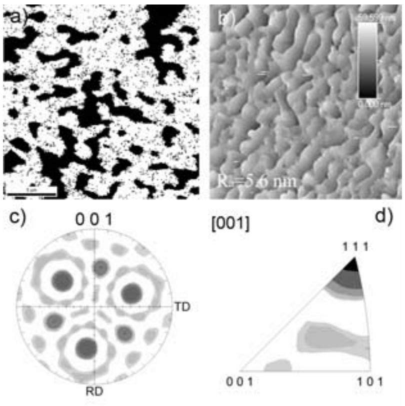

Fig. 3. Grain stucture and texture of 400 nm Al with **10 nm or 20 nm titanium** underlayer

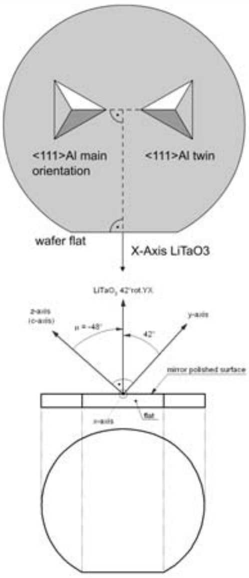

Fig. 4. In-plane-orientation of <111> Al on LiTaO₃

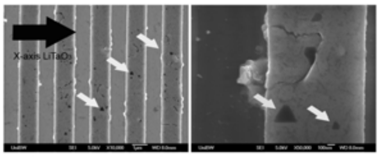

Fig. 5. Triangular grains sunk in the electrodes due to material migration in heavy loaded SAW devices

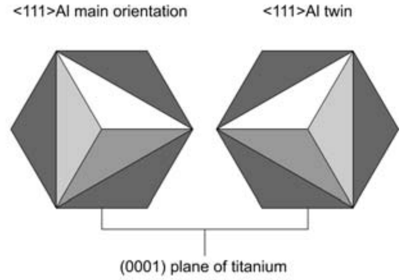

Fig.6. Alternatives of <111> Al to grow on titaniums (0001) plane