BAW technology – AlScN based RF filters

Helping customers keep the lead in 5G and beyond

Evatec Product Marketing Manager for Wireless applications ***Dr. Oguz Yildirim*** shows how the latest thin film processes for deposition of both piezoelectric layers and electrodes are helping customers keep leading performance in BAW filter technology.

CLUSTERLINE® 200 – The market leader in BAW

Evatec is already well established in delivering thin film production solutions for BAW technology. Previous edition of *LAYERS (LAYERS 6, page 60)* have already reported on the work developing production tools and processes for deposition of high Sc content Piezoelectric films of up to 30%. Today there are more than 150 Evatec modules working in 24/7 production around the world at uptimes higher than 95%. CLUSTERLINE® 200 which can be equipped with up to 6 single process modules and front end cassette or SMIF ports and ARQ 151 cathode technology utilizing 304mm diameter targets is the workhorse to deliver the excellent WiW thickness and stress uniformities demanded by our customers. Now however, our new generation ARQ320 cathode provides even better uniformities and longer lifetimes, improving the cost of ownership (CoO) by one more step.

Bulk acoustic wave (BAW) filters used in RF front end modules enables high speed, large bandwidth data transfer rates in our mobile phones paving the way for 6G, next generation communication (see Figure 1). BAW devices are based on a piezoelectric thin film excited via bottom and top electrodes that are in contact with the piezoelectric layers.

Figure 1: Bulk acoustic wave (BAW) filters.

8 out of 10 mobile devices on the market equipped with BAW RF filters contain Evatec layers

Piezoelectric layers

Taking AlScN performance to the next level by moving to Sc content >30at %

The ongoing move towards transferring larger amounts of data at even higher operating frequencies calls for higher scandium content and thinner films but this must be achieved without compromize on film quality. Average stress and its variance across the wafer must remain under control and film surface quality must be kept free of abnormally oriented grains typically seen at higher Scandium levels. And all this without any compromize on very low levels of edge exclusion on the wafer to maintain manufacturing process yield. Figure 2a shows the gains in piezoelectric coefficient possible by moving to higher scandium content, while Figure 2b shows the variation in electromechanical coupling coefficient as a function of film stress as reported in the literature. This reminds us of the importance of achieving excellent thickness uniformity and narrow stress range across wafers in production.

Typical process performance on 200mm in production is illustrated in Table 1, allowing customers to achieve the highest wafer utilizations with edge exclusion of only 5mm.

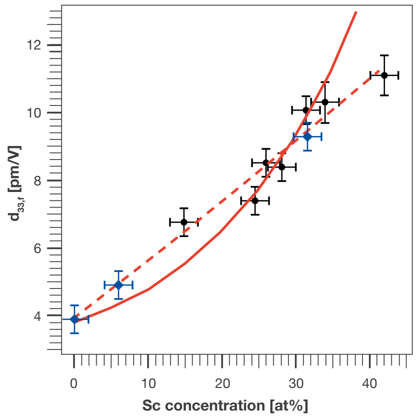

Figure 2a: $d_{33}f$ as a function of the Sc content. Solid red curve represents the value obtained from ab-initio calculation

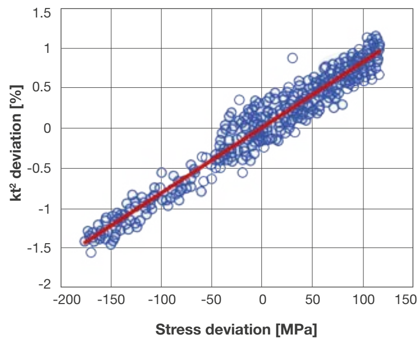

Figure 2b: Coupling coefficient vs stress for $Al_{0.7}Sc_{0.3}N$ film

$Al_{1-x}Sc_xN$ film performance on 200mm

Substrate	Film Parameter
Wafer diameter	200 mm
In film Sc concentration	Up to 39 at.%
Film thickness	500nm
Thickness uniformity (within wafer) 1sigma	<0.5%
Thickness uniformity (wafer to wafer) 1sigma	<0.3%
Refractive index @633nm wavelength	2.07
Average film stress range	-300 to +500 MPa (adjustable)
Film stress range (within wafer)	±75 MPA(@0.5% Uth) ±50 MPa (@ 1.0%Uth)
Stress repeatability (wafer to wafer)	±30 MPa
Rc <002>	< 1.5° (FWHM)

Table 1: Typical process performance

Surface quality of high scandium content films

Figure 3 shows the results by AFM obtained from $Al_{1-x}Sc_xN$ layers where x is varied from 20 at.% to levels higher than 36 at.% in the target material resulting in $Al_{1-x}Sc_xN$ layers with average Sc concentrations up to 39.7 at.%. These were produced on a CLUSTERLINE® 200 using a "manufacturing ready" single target source. These layers have been qualified at a wafer and device level. Based on the results we show the deposition path towards the experimentally achievable limit of Sc doping. However, Sc atoms in the AlN lattice can also lead to defects resulting in abnormally oriented grains (AOGs) or depending on the growth conditions phase segregation. Formation of such defects is the biggest challenge for growing highly uniform, stress neutral $Al_{1-x}Sc_xN$ thin films while can already offer production ready solution for Sc concentrations up to ~40at.%.

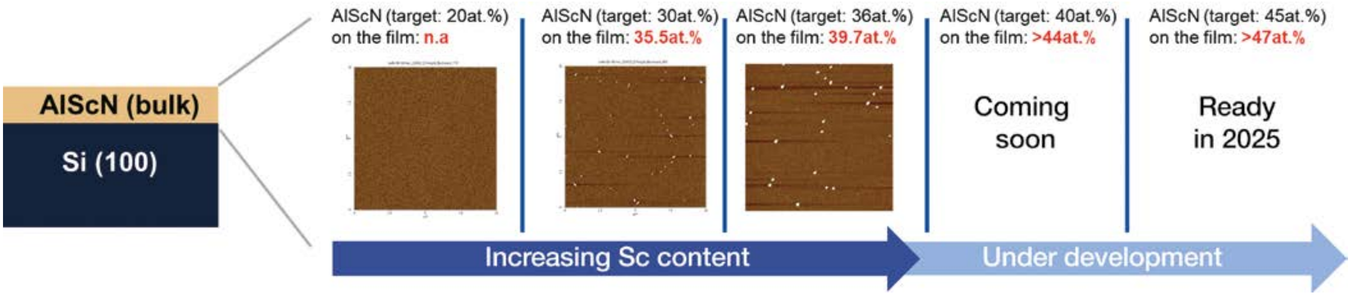

Figure 3: AFM image of $Al_{1-x}Sc_x$ N layers for varying Sc doping levels and 500nm thickness. All these layers were grown during production simulation depositions on 8 inch wafers, and have thickness uniformities <0.5 % (1 sigma), neutral average stress and stress range <150MPa. Sc concentration of the target consistently varies from the measured average Sc concentration in the film.

Electrodes

Delivering the best piezoelectric layers may rightly get lots of attention, but that's not the whole story and we can provide unique solutions for electrode production that provides flexible processes.

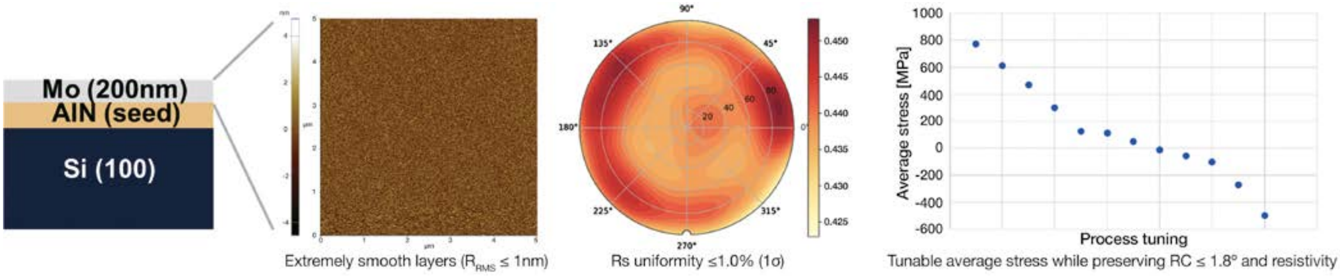

Figure 4: Performance of standard production solution of Evatec Mo layers grown on polycrystalline seed layers. From left to right are; schematic of layers, AFM image, Rs map and average stress data. Average stress is tuned while the other layer properties kept the same.

Current state of the art

Evatec's existing hot Electrostatic Chuck (ESC) technology is already well known as a standard production solution for tuneable electrode deposition processes delivering smooth, highly conductive layers and controlled stress. Our standard production solution gives the flexibility to tune the average stress of the electrode layers while maintaining the basic film performance such as the crystal quality, resistivity and uniformities. Typical results are shown in Figure 4. Further development can be done utilizing our unique sputtering based epitxial seed layer solution prior to electrode deposition. This results in a significant improvement in specific resistivity, roughness and crystal structure without increasing the deposition temperature during the growth of the Mo layer. The results are shown in Figure 5.

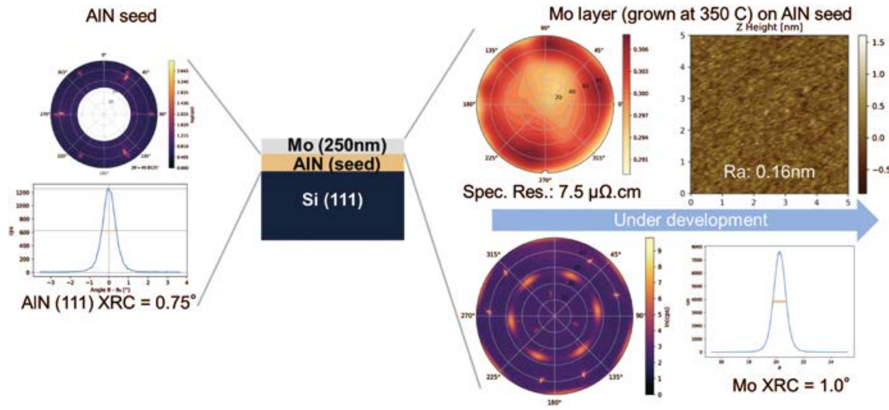

Figure 5: Properties of Epi-AlN seed layer (left) and Mo layer grown on Epi-AlN seed layer (right).

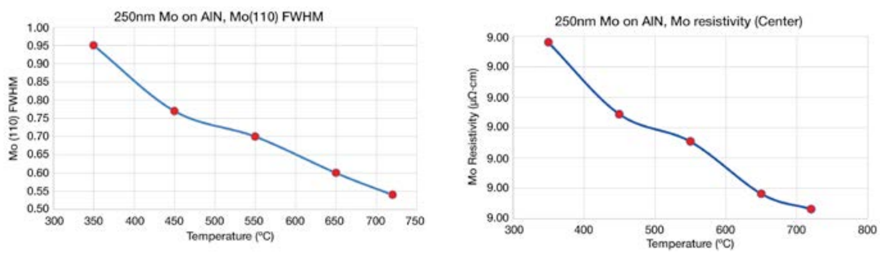

Figure 6: Properties of new generation, very hot Mo layers grown on Epi-AlN seed layers. FWHM of the Mo(110) rocking curve (left), and resistivity (right).

Electrode processes – The future is already here!

Often the electrode materials chosen for BAW applications are so-called high melting point materials comprising of elements such as W, Mo, etc. Further improvement on layers based on these materials thus require production solutions at high temperature. The most recent developments at Evatec are focused on offering customers Very Hot Chuck (VHC) capability at temperatures up to 750ºC and with it, the possibility to achieve significant reductions in resistivity and improvement in the film crystallinity that enhances the device performance dramatically as shown in Figure 6.