# Epitaxial Materials for RF filters

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**Abstract**

**In this talk the authors will highlight a filter with all epitaxially grown layers which include epitaxial metal and ScAlN. Results for the epitaxial metal will show films of molybdenum with resistivities comparable to that of bulk metal in films with thicknesses down to 50nm. Initial test show resonance frequencies of 4.3GHz with 3dB-bandwidth quality factor ($Q_{3\text{-db}}$) over 1000**

## INTRODUCTION

BAW filters and associated variants such as Film FBAR and SMR filters will be the dominant filter technology for 5G, operating at frequencies in the 3-8GHZ range and higher. For these types of filters, the current technology uses sputtering to deposit metal contacts and piezoelectric layers (typically AlN and ScAlN) onto 200mm silicon wafers [1-3]. As frequency and performance requirements of BAW filters increase, it is expected that the quality and controllability of sputtered material may ultimately limit device performance. One way to overcome such limitations is to use epitaxy for metal contact and piezoelectric layer deposition. Epitaxially grown materials have been shown to have better electrical and mechanical properties and improved acoustic velocity, heat conduction, and reliability [4-5]. Furthermore, increased frequency requires a reduction in all layer thicknesses, including the electrodes, without loss of performance making epitaxy an obvious choice for deposition. Finally, an epitaxial filter may enable higher levels of integration given that the epitaxial process could be extended to additional III-N device layers in the same epi stack. IQE has leveraged its core competency in epitaxial growth and its proprietary cREO™ technology to develop a unique BAW filter capability that incorporates thin, low resistivity epitaxial metal contacts and epitaxial rare earth-III-N piezoelectric layers. Resonator results will be presented for a device using epitaxial Mo/ScAlN layers on the cREO™.

## EPITAXIAL METAL

A key challenge for the epi-metal process is preventing the formation of a metal silicide. To overcome this issue, IQE has employed its patented crystalline rare earth oxide (cREO™) technology to act as a chemical barrier between the metal layer and the underlying silicon wafer. The cREO™ template also provides the crystal registry for the growth of <110> molybdenum, the metal chosen for the initial prototypes. Typical data for the Mo layers on cREO exhibit a XRD <110> rocking curve FWHM in the range of 0.8 to 1° and a 20µm x 20µm area surface roughness RMS between 1.1 to 1.3 nm. In the XRD theta scan shown in Figure 1 there are no additional peaks observed from any Mo-Si alloying confirming the cREO is a robust barrier at the process temperatures used.

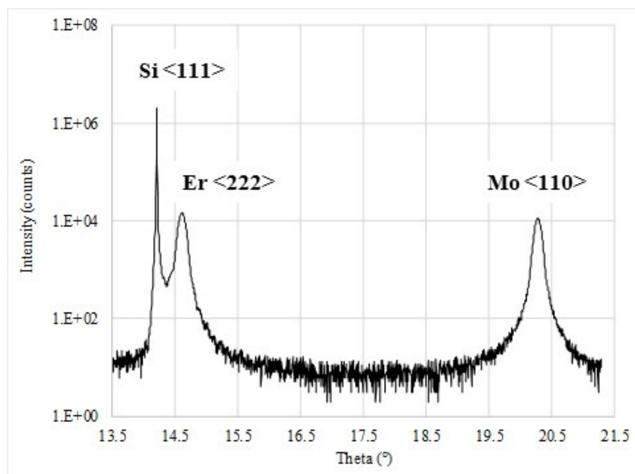


Figure 1: X-ray theta scan for epitaxial metal on cREO™ / silicon template

Resistivity data for epitaxial Mo on cREO is given in Figure 2. For an 100nm epitaxial Mo layer grown on a cREO layer the measured sheet resistivity is equivalent to the published bulk resistivity of Mo (5.34 x $10^{-8}$ Ω-m). Epilayers as thin as 20nm have been successfully grown; at 40nm the deviation from an ideal metal layer is <20%.

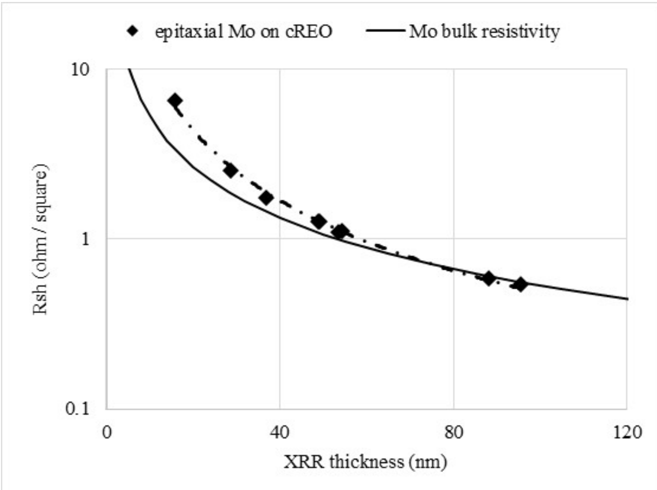


Figure 2: Sheet resistivity data fir epitaxial molybdenum on cREO™ / silicon template

DEVICE EVALUATION

Initial device evaluation focused on ScAlN grown directly on silicon with the manufacture of both SAW and LWR devices in order to assess the quality of the epitaxial piezoelectric material. LWR devices exhibited a resonance at 8GHz (Q=740, $k_t^2$ = 5.3%) due in part to the fact that a 400nm epi layer can support the necessary IDT pitch whilst meeting key design criteria [6]. The SAW resonator data (Q=970, $k_t^2$ = 7.4%) will be presented at IMS2019 [7]

Here we present data for a single thickness mode resonator using an FBAR type architecture. The design of the epi stack in shown in Figure 3 The piezoelectric region that has an average Sc concentration of 9%. As can be seen from the X-TEM image in Figure 3 the epitaxial cREO and metal layers exhibit sharp interface at each material boundary along with a high degree of thickness uniformity.

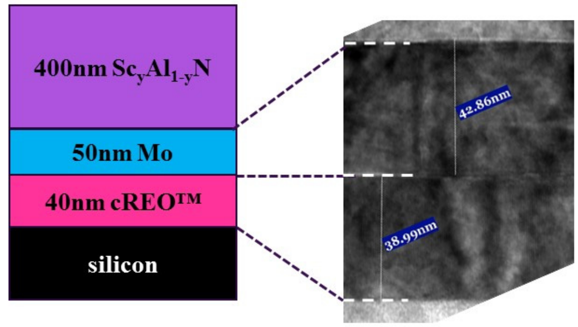


Figure 3: X-TEM and layer schematic for FBAR evaluation stack

The device processing used the cREO as the base for both top and bottom electrodes with the air gap created by a $XeF_2$ release etch. The cREO was also used as the etch stop for patterning the bottom Mo electrode. A schematic of the test structure used in shown in Figure 4.

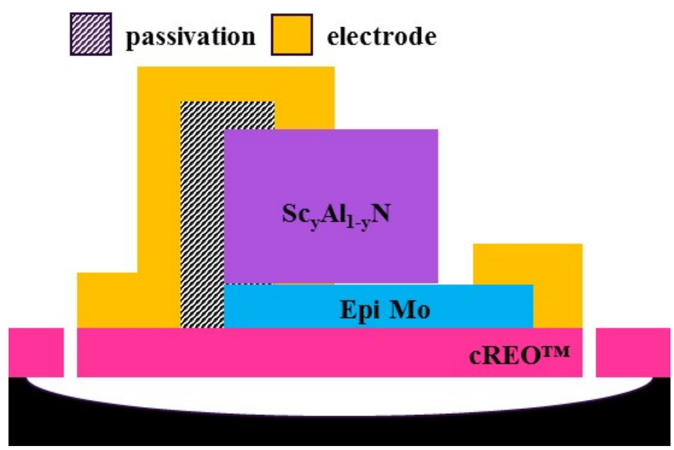


Figure 4: Schematic of the FBAR evaluation structure

Figure 5 shows the SEM image for a completed 40umx60um resonator. Fig 6 shows the S11 frequency response of the thickness mode resonator, with a resonance at 4.13GHz. Using the 3 dB method outlined in [7] the extracted value of $Q_{3\text{-dB}}$ 1080 . This is shown in the inset plot of figure 6.

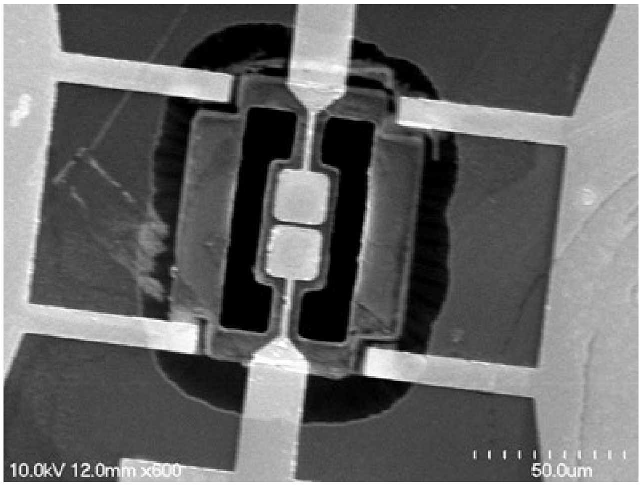


Figure 5: SEM image of the completed thickness-mode resonator

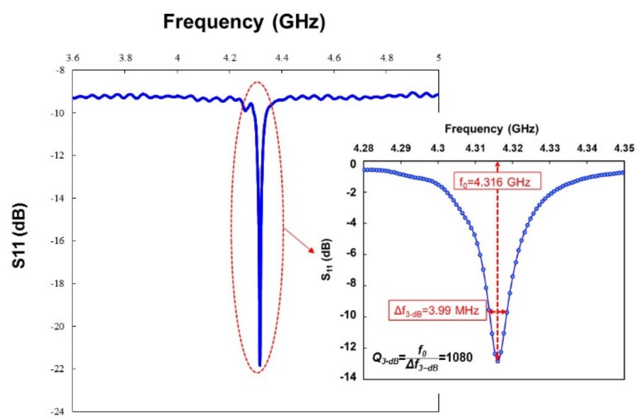


Figure 6: S11 frequency response of a 40umx60um resonator Inset is the zoomed in 4.13 GHz resonance peak showing extracted 3dB Q value

A more rigorous extraction of Q is underway. In addition different device layouts, the use of DRIE based air cavity and various epitaxial stacks will be tested for comparison and determination of the epitaxial parameters that drive the current acoustic properties.

## CONCLUSIONS

In summary we have described a new approach to the use of epitaxially grown materials in RF filters. This approach combines a crystalline rare earth oxide (cREO™) template with epitaxial metals that demonstrate bulk like resistivities down to 50nm. Epitaxial ScAlN is then grown directly on the metal surface. This epitaxial approach has been used to demonstrate resonators in SAW, LWR and FBAR configurations. For the latter we have shown resonance at 4.13GHz with an extracted $Q_{3\text{-dB}}$ of >1000

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## ACRONYMS

BAW: Bulk Acoustic Wave
FBAR: Film Bulk Acoustic Resonator
SMR: Solidly Mounted Resonator
cREO: crystalline Rare Earth Oxide
XRD: X-Reay Diffraction
SAW: Surface Acoustic Wave
LWR: Lamb Wave Resonator
DRIE: Deep Reactive Ion Etch