CLUSTERLINE® 200 II IS READY

MASS PRODUCTION OF HIGH SCANDIUM CONCENTRATION $Al_{(1-x)}Sc_{(x)}N$ FILMS!

LAYERS UPDATE

Evatec's **Dr. Bernd Heinz** explains the latest step forward in delivering an economical mass production solution for high performance piezoelectric films.

Why AlScN?

Its strongly enhanced piezoelectric response [1] makes aluminum scandium nitride ($AlSc_xN$) a very promising candidate for use in next generation RF filter devices, microphones and speakers, energy harvesting devices, piezoelectric micro-machined ultrasonic transducers and many other sensors and actuators. The industrial use of $AlSc_xN$ requires a reliable deposition technology to control the growth of films in the correct (002) textured wurtzite structure within tight specifications regarding uniformity and repeatability. Further, the process has to be mastered on multiple substrate and electrode materials due to the wide variety of possible applications.

The challenge

In a previous edition of LAYERS, we reported $AlSc_xN$ films grown using Evatec Multisource Technology – a unique solution for deposition of $AlSc_xN$ films by co-sputter of metallic aluminum and scandium targets. It enables the deposition of films with any desired Sc concentration independent of the availability of $AlSc_x$ compound targets.

For single target deposition of high uniformity $AlSc_x$ compound films, targets with the size of 300mm diameter are required to coat 200mm substrates uniformly. Until now such targets have only been available with a limited Sc concentration below 10at%. Quite recently, target manufacturers succeeded in providing the first 300mm prototype targets to Evatec with a high scandium concentration. This article will report on $AlSc_xN$ films sputtered from 300mm single compound targets with a nominal Sc concentration of 30at%. The obvious advantages of using larger compound targets instead of co-sputtering technology is the increased productivity (by a factor of 5) and significantly better film uniformity – in particular thickness and stress.

Please note that AlScN technology is subject to a number of patents and/or patent applications. Evatec recommends that customers check the patent situation within their field of business carefully and secure licenses if necessary prior to the start of their commercial production.

Results

Standard AlN deposition technology available on the Evatec CLUSTERLINE® 200 II single wafer production tool was used for the $AlSc_xN$ trials. Films were deposited on 200mm substrates with a film growth rate of about 1nm/s at a temperature of 300°C. The Sc concentration in the films was verified by EDX analysis. It turned out that the in-film Sc concentration is slightly higher than the nominal target composition. Depending on the specifics of the available targets, Sc concentration values of 31at% to 34at% were measured in the films.

The piezoelectric response for an $AlSc_{31}N$ film sputtered from a 300mm compound target is highlighted in Fig. 1 where it is compared with selected films made by different methods on the Evatec CLUSTERLINE® 200 II. All values were determined using a Piezotest PM300 tester. Each data point represents the average value of d33 measured at different positions on each substrate while the bars indicate the variation of the piezoelectric response within one substrate. The increase of the d33 values with increasing scandium content is in good agreement with the piezoelectric response reported by Akiyama [1]. The value of 16.1 pC/N for the single target sputtered film with a composition of $AlSc_{31}N$ confirms our ability to match the Akiyama results even for higher Sc concentrations with a film grown under production relevant conditions.

To enable production with high yield the control of the film stress uniformity across the 200mm substrate is key. Any larger variation in the stress value will directly affect device properties as the electromechanical coupling coefficient kt2 of $AlSc_xN$ films depend directly on the film stress. With the newly developed AlN process hardware film stress uniformity results of better ± 100MPa across a 200mm wafer can be achieved, as demonstrated in Fig.2.

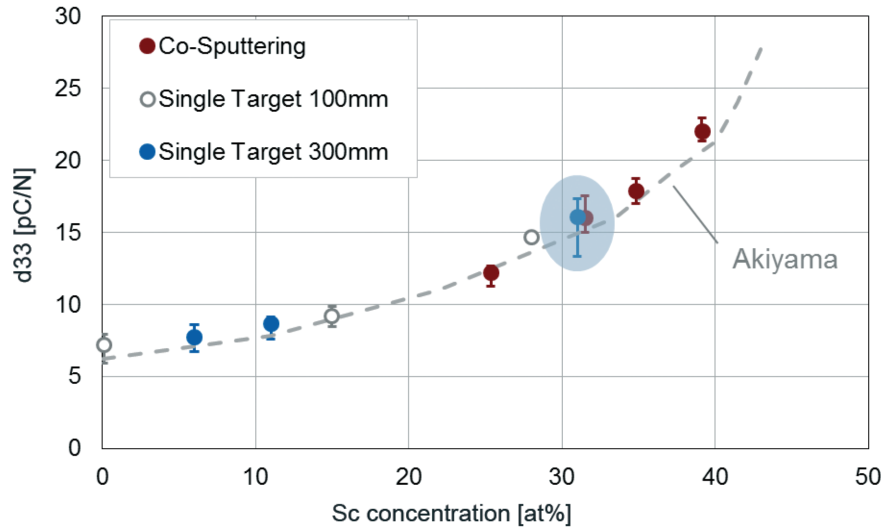

Fig. 1: Measured d33 values for $AlSc_xN$ with a Sc concentration between 0 at% and 39 at%. The result achieved by sputtering the 300mm $AlSc_{30}$ compound target is highlighted. For comparison, the data from Akiyama [1] is shown.

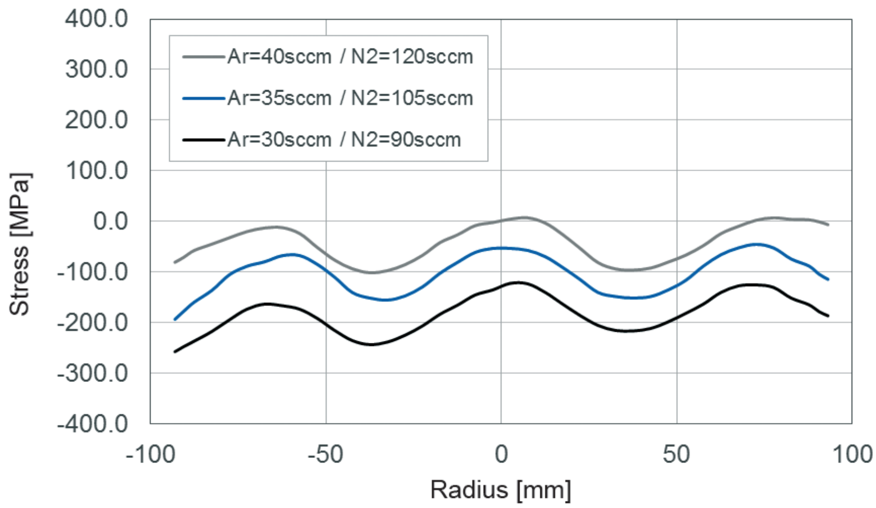

Fig. 2: Stress uniformity for $AlSc_{31}N$ across a 200mm wafer with an edge exclusion of 7mm. Results for 3 different process settings are displayed.

Substrate / Electrode	RC (FWHM)
Pt (111)	1.1°
Si (100)	1.2°
Mo (110)	1.3°

Table 1. XRD rocking curve values (FWHM) measured around the (002) diffraction peak for 1000nm thick $AlSc_{33}N$ films grown on different surfaces.

The XRD rocking curve values (FWHM) measured around the (002) diffraction peak are the commonly used quantity to rate the crystalline quality of $AlSc_xN$ films. Table 1 summarises the rocking curve values for 1000nm thick $AlSc_{33}N$ films grown on bare and metallised Si substrates. Excellent values below 1.5° were achieved on well textured Pt(111) and Mo(100) electrodes as well as on bare silicon wafers.

The $AlSc_{33}N$ films deposited either on Pt or Mo electrodes or directly on silicon show high crystalline quality in the XRD measurement. However, AFM images (Fig.3) reveal significant differences in surface morphology correlating with the different types of substrate. The appearance of elevated, cone-like grains, presumably formed by miss-oriented $AlSc_xN$ crystallites which are embedded in a matrix of the preferred (002) oriented crystallites can be observed. $AlSc_{33}N$ films grown on Si and on Mo are affected more severely compared to $AlSc_{33}N$ films grown on Pt. The number of unwanted crystallites is significantly suppressed in the films grown on Pt electrodes. The appearance of these crystallites is a well-known phenomenon, associated with increasing Sc concentration. The appropriate type and condition of the substrate surface is key to mitigate the appearance of these grains. Deposition at reduced sputter pressure or the introduction of an AlN seed layers are known countermeasures to minimise their number but the deposition of $Al_{(1-x)}Sc_xN$ films with Sc concentration higher than 30% on other than Pt electrodes remains an ongoing challenge.

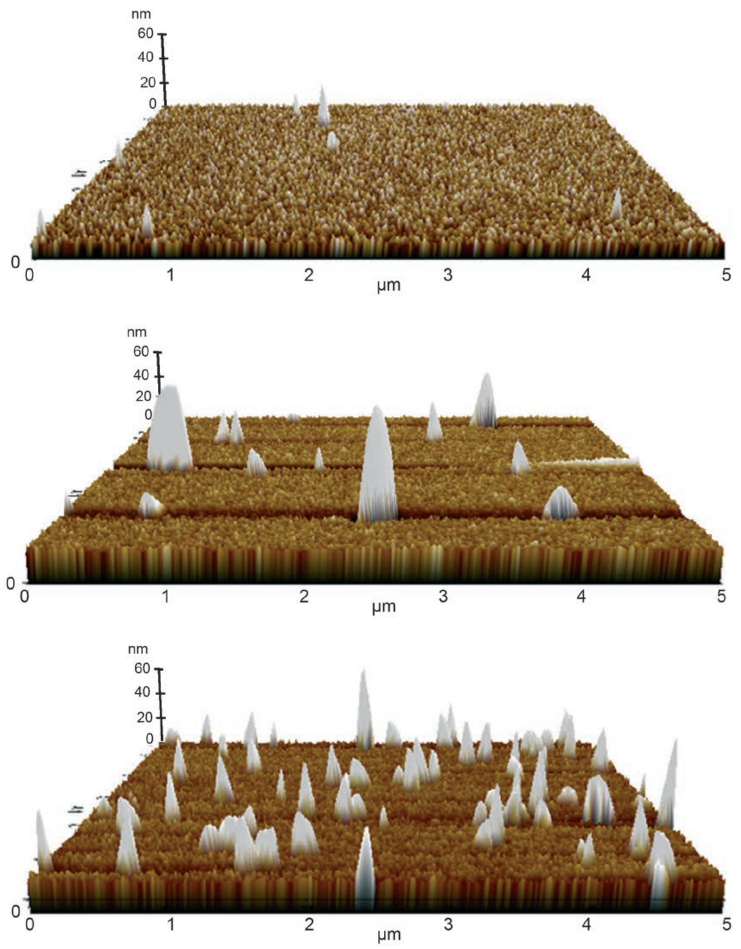

Fig. 3: AFM image of 1000nm thick $AlSc_{33}N$ films deposited on on (a) Pt (111) electrode (b) bare silicon and (c) on Mo(110) by sputtering a 300mm compound target. (a, b, c, still missing in the picture)

[1] M. Akiyama, K. Kano, and A. Teshigahara, Appl. Phys. Lett. 95, 162107 (2009).

The road ahead

Evatec is currently witnessing an increasing demand for new piezoelectric materials. $AlSc_xN$ is still in pole position amongst the possible candidates and preparation for 5G mobile communication is recognised as one of the major driving forces.

Even though films with scandium concentrations well below 30% will be seen in mass-production initially, Evatec's capability in mastering the challenges of $AlSc_xN$ film deposition with higher Sc concentration means we will be well placed for future demands in this industry.