SPUTTER DEPOSITION OF PIEZOELECTRIC AlN AND AlScN FILMS FOR ULTRASONIC AND ENERGY HARVESTING APPLICATIONS

Fraunhofer FEP

D. GLOESS[1)], S. BARTH[1)], H. BARTZSCH[1)], P. FRACH[1)], T. HERZOG[2)], S. WALTER[2)], H. HEUER[2)], G. SUCHANECK[3)], G. GERLACH[3)], J. JUUTI[4)], J. PALOSAARI[4)]

1) FRAUNHOFER INSTITUTE FOR ELECTRON BEAM AND PLASMA TECHNOLOGY FEP, WINTERBERGSTRASSE 28, DRESDEN, GERMANY
2) FRAUNHOFER INSTITUTE FOR NONDESTRUCTIVE TESTING DRESDEN BRANCH IZFP-D, MARIA-REICHE-STRASSE 2, 01109 DRESDEN, GERMANY
3) TECHNISCHE UNIVERSITÄT DRESDEN, SOLID-STATE ELECTRONICS LABORATORY, 01062 DRESDEN, GERMANY
4) UNIVERSITY OF OULU LINNANMAA, MICROELECTRONICS AND MATERIAL PHYSICS LABORATORIES,90014 OULU, FINLAND

INTRODUCTION / MOTIVATION

AlN - A PROMISING MATERIAL FOR THIN FILM PIEZOELECTRIC DEVICES

Aluminum-Nitride thin films are known and used since 1990s, mostly for resonator devices like SAW filters

- c-axis orientation necessary for thickness vibration
- low temperature deposition process possible
- can be combined with conventional semiconductor manufacturing processes
- high temperature stability

Potential applications:

- ultrasonic wave devices
- SAW and BAW devices
- energy harvesting
- LED's

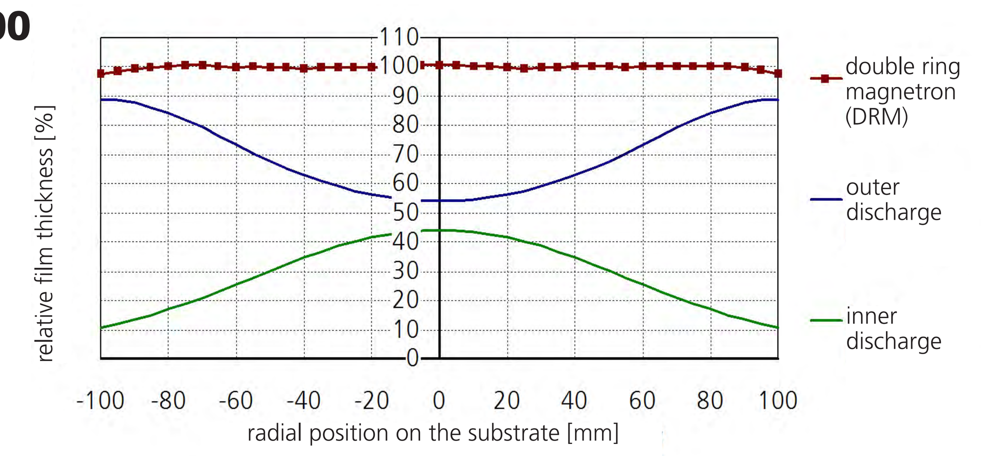
CHARACTERISTICS OF PULSE MAGNETRON SPUTTER PROCESS

- excellent process *stability* and *reproducibility*
- stoichiometric compound layers (e.g. AlN, SiO_2, Al_2O_3, TiO_2) with very *low absorption and high barrier properties* (electrical insulation, diffusion barrier)
- deposition of *dense climatically stable films* by intense energetic substrate bombardment during deposition
- very high deposition *rates* (e.g. AlN: 3 nm/sec)
- *uniform* coating of large substrates
- efficient methods of substrate *pre-treatment* by plasma processes to ensure good layer adhesion

EXPERIMENTAL

HARDWARE AND TECHNOLOGY FOR AlN DEPOSITION - DOUBLE RING MAGNETRON DRM 400

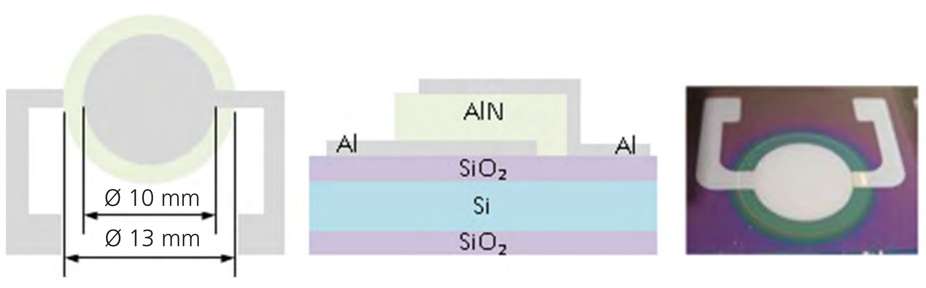
- reactive pulse magnetron sputtering (PMS) from metallic Al target
- deposition rate: 3 nm/s
- substrate size: Ø 200 mm
- film thickness uniformity: up to ±0.5%
- layer thickness: up to 50 µm



Superposition of film thickness distributions of two concentric discharges.

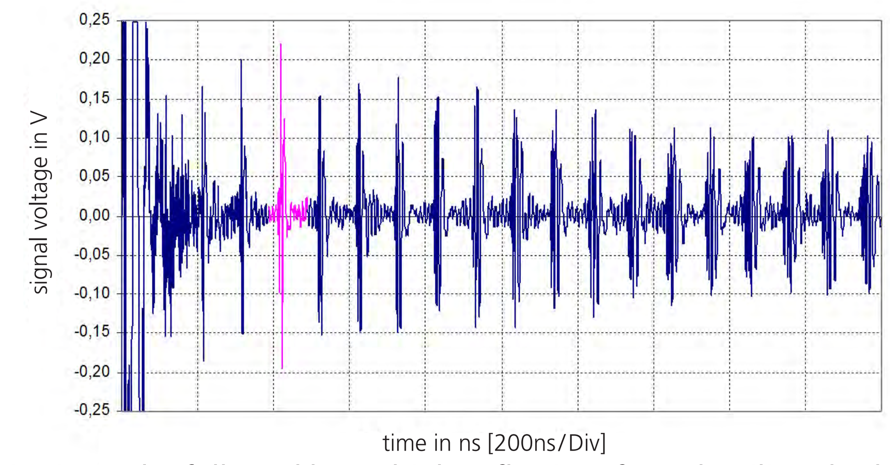
Double ring magnetron (DRM 400) for uniform coating of Ø 200 mm (8") substrates.

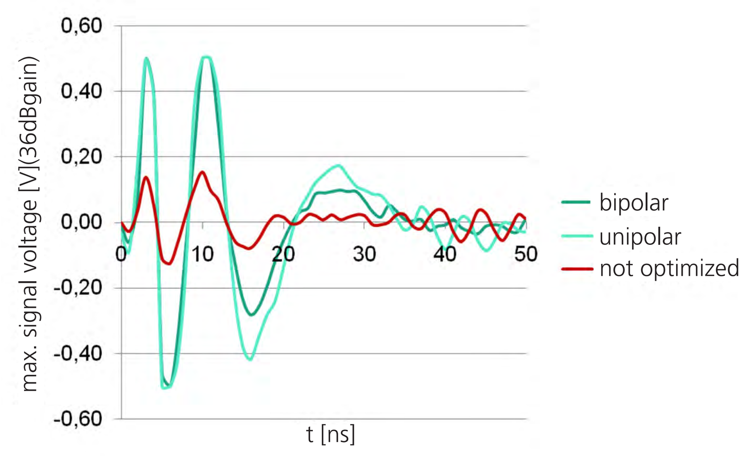
PULSE ECHO MEASUREMENTS AS DEMONSTRATION FOR US SENSORS



Measurement principles:

- berlincourt piezometer PM 300 (piezotest) for piezoelectric charge constant (d_{33})
- pulser/receiver setup (DPR500, JSR Ultrasonics) with PC digitizer card for pulse echo measurements

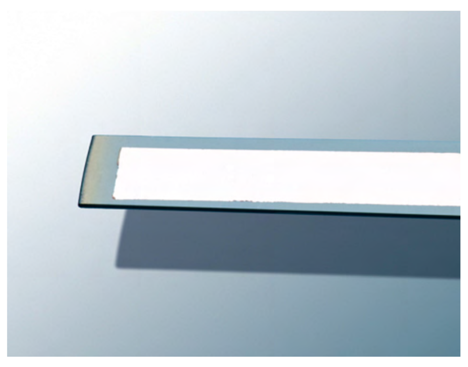




Excitation pulse followed by multiple reflections from the silicon backside.

ENERGY HARVESTING

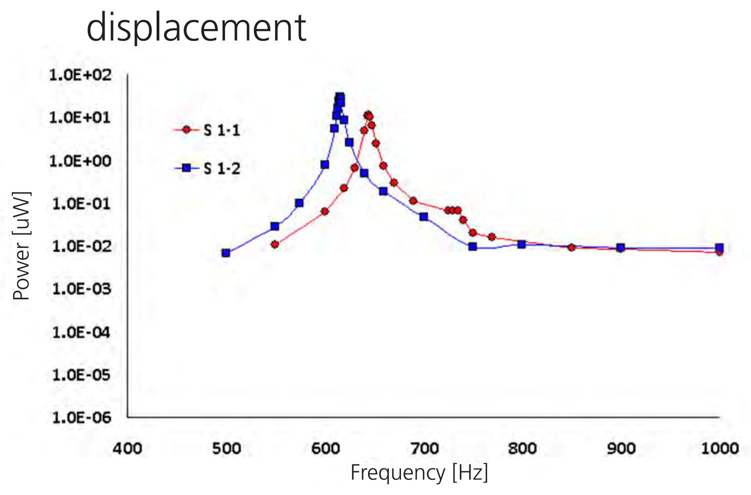
- samples were put into mechanical base and vibrated by a shaker as a function of frequency
- constant excitation of approx. 5 µm peak-to-peak displacement for mechanical base was maintained for each frequency
- displacement of the tip of the samples was recorded at the resonance frequency by vibrometer measurement
- generated power was measured as a function of resistive load, measurement by multimeter connected in parallel to the load
- maximal generated power in resonance and using optimal load



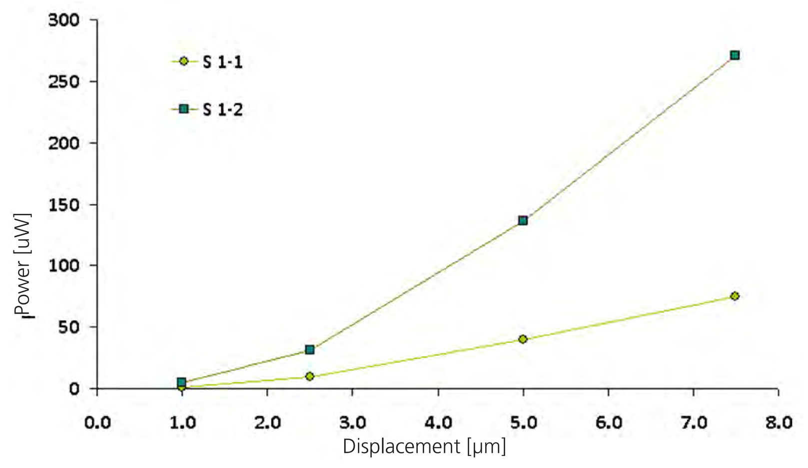
RESULTS

ENERGY HARVESTING PROPERTIES OF AlN LAYERS

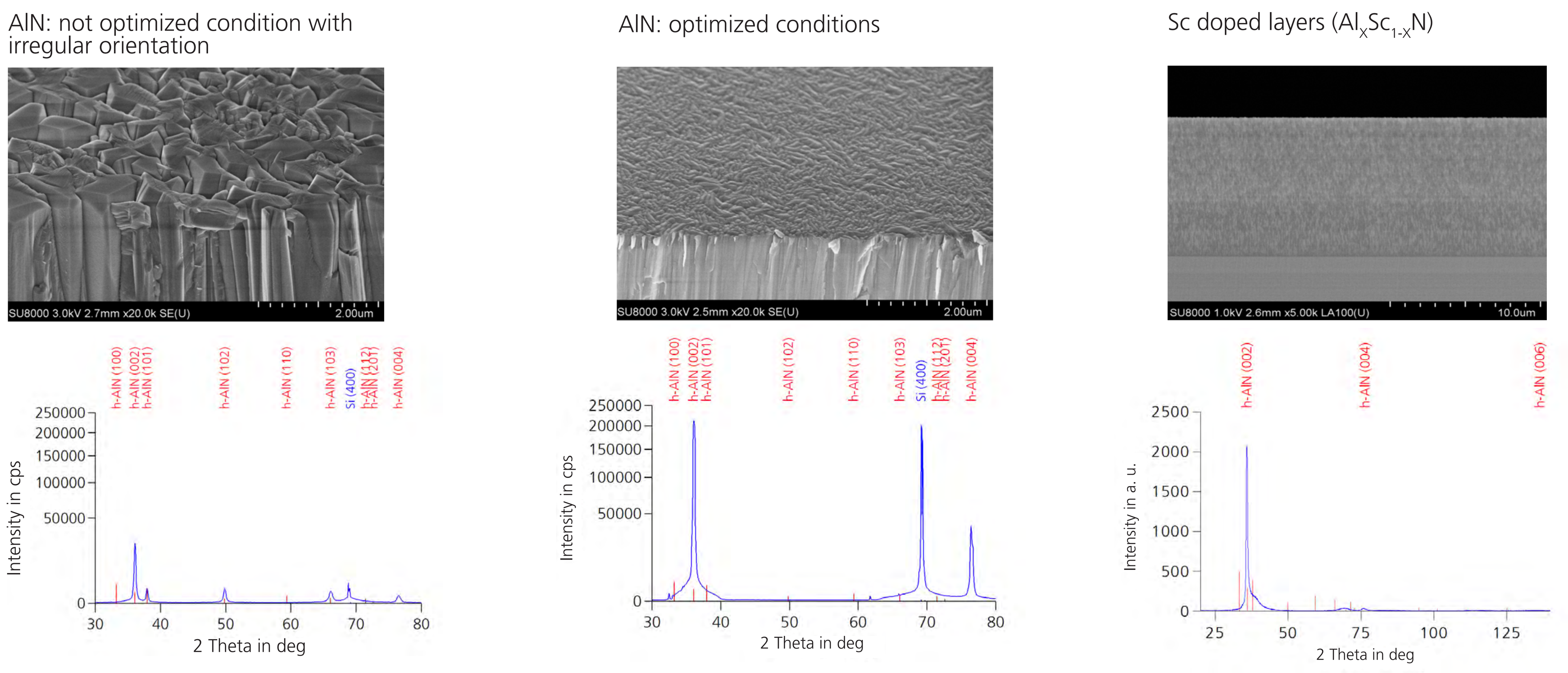
- size of energy harvesters: 8 × 80 mm (substrate thickness: 0.57 mm; layer thickness: 10 … 50 µm)
- 1st/2nd resonance frequency was observed at approx. 150 Hz/700 Hz
- best samples showed average (RMS) power of 141 µW at optimal resistive load and 5 µm base displacement



Power output vs. frequency (80 kΩ load, 2.5 µm base displacement)



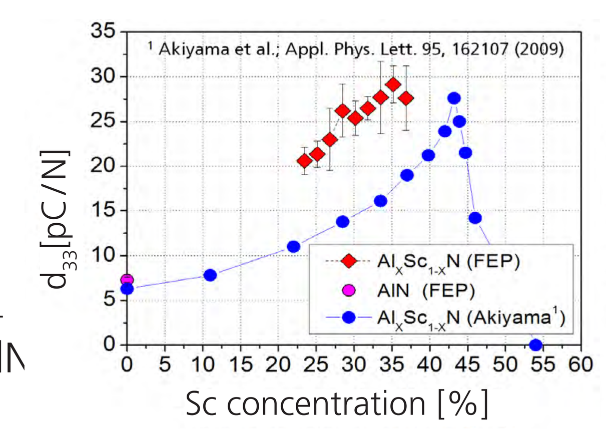
Average power output vs. displacement(at optimal resistive load and resonance frequency)

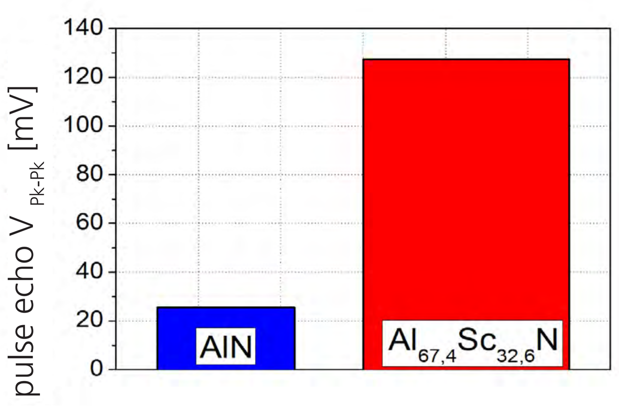


d_{33}=0.6 pm/V d_{33}=7.2 pm/V d_{33}=29 pm/V

SCANDIUM-DOPING ($Al_xSc_{1-x}N$)

- reactive Co-Sputtering from metallic Al- und Sc-Targets
- deposition rate: 2 nm/s
- improvement of d_{33} up to 30 pC/N
- signal level of pulse-echo-measurement of $Al_xSc_{1-x}N$ in comparison to AlN show same increase as d_{33}





CONCLUSION

- deposition of AlN films by reactive pulse sputtering at high deposition rate was successful
- piezoelectric coefficient on unheated substrates:
  AlN: d_{33}=7.2 pm/V $Al_xSc_{1-x}N$: d_{33}=29 pm/V
- application e.g. in SAW, BAW, LED, ultrasonic transducers, energy harvesting, …
- AlN shows lower d_{33} than PZT - However, it is well suited for energy harvesting applications, because of it's high acoustic velocity and relatively high d_{31}
- measurements of energy harvesting properties of $Al_xSc_{1-x}N$ are under progress

CORRESPONDING CONTACT

Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik FEP

Winterbergstraße 28
01277 Dresden, Germany

www.fep.fraunhofer.de

Dr. Daniel Glöß
daniel.gloess@fep.fraunhofer.de

Phone: +49-351-2586-394
FAX: +49-351-2586-55-394

corresponding contact

Fraunhofer FEP   Fraunhofer IZFP   TECHNISCHE UNIVERSITÄT DRESDEN   UNIVERSITY of OULU OULUN YLIOPISTO

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