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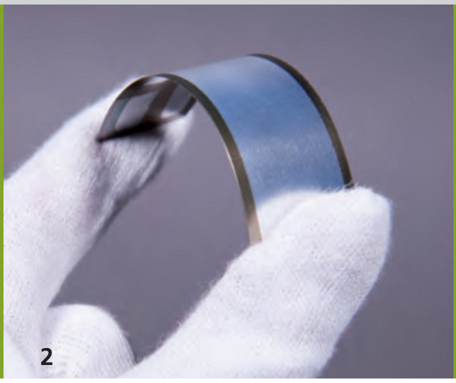

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1 *Energy harvesting demonstrator*
2 *Steel strip coated with AlN*
3 *Cluster 300 test plant for stationary magnetron sputtering*

ENERGY HARVESTING WITH PIEZOELECTRIC MATERIALS

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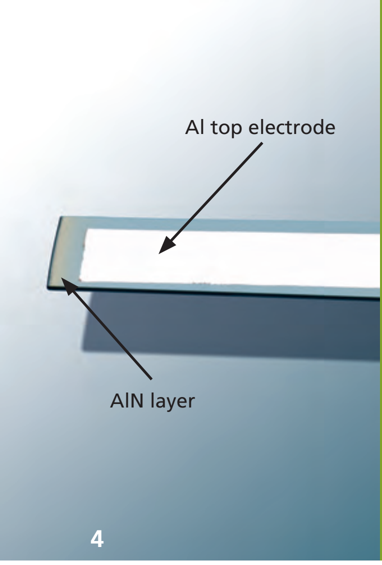
Introduction

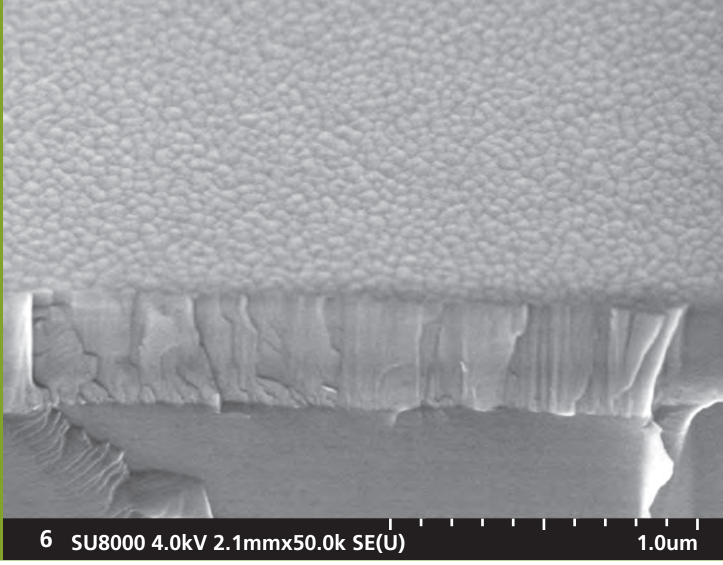
Currently, an increasing demand for autonomous sensors and systems with wireless radio connection and autonomous energy supply can be observed. This is in part due to the strong trend towards continually smaller mobile systems and the increasing market for “wearables”.
The energy supply of such systems by means of batteries or cables is often too complicated or complex. One solution provides the on-site energy generation from the environment – the so-called energy harvesting. Depending on the requirements and environment, it can be realized for example by solar cells, thermoelectric or piezoelectric materials. Here, new piezoelectric materials and technologies for their production are being introduced to convert mechanical energy (deformation, vibration) into electrical energy.

Magnetron sputtering of piezoelectric materials at Fraunhofer FEP

Piezoelectric materials have the characteristic behavior of deforming when an electrical voltage is applied or having charge separations when put under mechanical force. With the latter aspect, they can convert mechanical vibrations into electric energy. The most common material for piezoelectric applications is lead-zirconate-titanate (PZT).

Aluminum nitride (AlN) is an alternative material. While aluminum nitride has a significantly lower piezocoefficient d_{33} compared to PZT, this is (at least partially) compensated by a considerably lower dielectricity and more advantageous mechanical characteristics. Its special advantages over PZT are that it is lead-free according to EC regulations, its stability, its biocompatibility as well as the





fact that the deposition of AlN is compatible with common microelectronic processes.

Fraunhofer FEP developed a process to deposit AlN layers with piezo coefficients of up to 7 pC/N successfully while maintaining moderate film stress. The layer deposition was made by reactive magnetron sputtering of aluminum targets in an argon-nitrogen atmosphere. The deposition processes were carried out in a stationary coating arrangement with a double-ring magnetron sputtering source (DRM 400). Due to the superposition of discharges of both targets, it is possible to deposit extremely homogenous layers on a diameter of up to 200 mm and to achieve high coating rates at the same time. Apart from piezoelectric aluminum nitride layers a large number of other materials can be deposited, e.g. metals, oxides, nitrides, gradient layers or multilayers. These materials can be used a electrode, insulation or stress compensation layers, for example.

Additionally, aluminum scandium nitride ($Al_xSc_{1-x}N$) layers with variable Al:Sc ratio were deposited by means of reactive co-sputtering of aluminum and scandium targets. Compared to pure AlN these layers showed a significantly higher piezo coefficient d_{33} of up to 27 pC/N at similar coating rates and moderate film stress (Table 1).

Energy harvesting measurement results

A measurement system for the characterization of energy harvesting solutions by means of AlN layers was developed by Fraunhofer FEP in cooperation with the Dresden University of Technology (Fig. 5). It consists of an electromagnetic shaker system for the generation of defined mechanical vibrations (frequency / displacement). A silicon strip with piezoelectric thin film (AlN or $Al_xSc_{1-x}N$) is excited to oscillate. The power is calculated by measuring the generated voltage at resonance (Table 2). It is sufficient to supply low-power electronics (e.g. sensors).

Furthermore, measurements were carried out on steel substrates (75 mm × 25 mm) which were coated with $Al_{0.67}Sc_{0.33}N$ (Fig. 2) and exposed to a single excitation with a manual deflection of 2 cm. Per excitation, 420 µJ was measured including the resulting oscillation.

Table 1: Comparison AlN / $Al_xSc_{1-x}N$ depositions

	AlN	$Al_xSc_{1-x}N$
layer thickness [µm]	10	10
max. d_{33} [pC/N]	7	27
deposition rate [nm/min]	100 … 200	100 … 200
film stress	customer-specific	

Table 2: Examples of measured AC power at ±2.5 µm deflection of the shaker

material	thickness [µm]	length Si oscillator [cm]	P_{rms} [µW]
AlN	10	8	70
AlN	50	8	141
$Al_{0,6}Sc_{0,4}N$	10	6	350

Our offer

- Application-specific layer depositions of AlN and $Al_xSc_{1-x}N$ (e.g. for energy harvesting)
- Optimization of materials and coatings for further fields of application (ultrasound generation, resonance filter, actuators)
- Hardware and technology development for coating equipments
- Electromechanical simulations

Applications

- Autonomous on-site energy generation for sensor applications
  - Transport / Logistics
  - Aerospace
  - Mechanical engineering
  - Monitoring
  - Medical technology

4 AlN layer on Si-substrate as oscillator of Energy Harvester

5 Silicon strip with piezoelectric thin film in the measurement system

6 SEM micrograph of an AlN layer in optimized condition for energy harvesting

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