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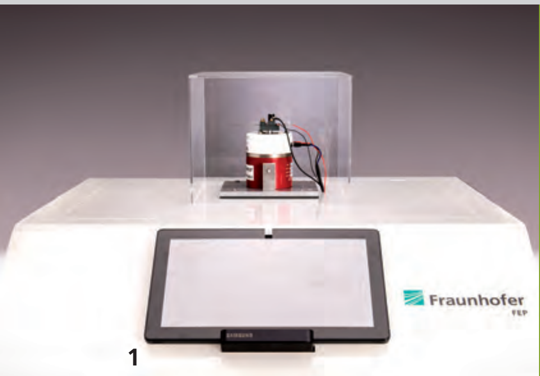

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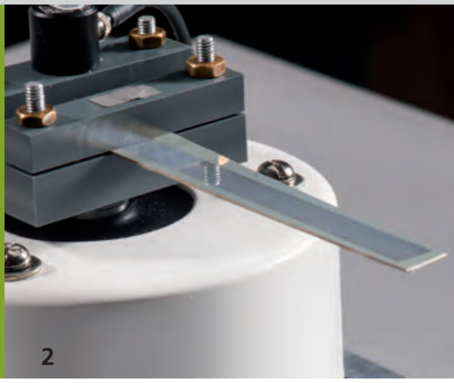
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**1** *Energy harvesting demonstrator*
**2** *Silicon cantilever with piezoelectric thin film layer*
**3** *Cluster 300 test plant for stationary magnetron sputtering*

# ENERGY HARVESTING


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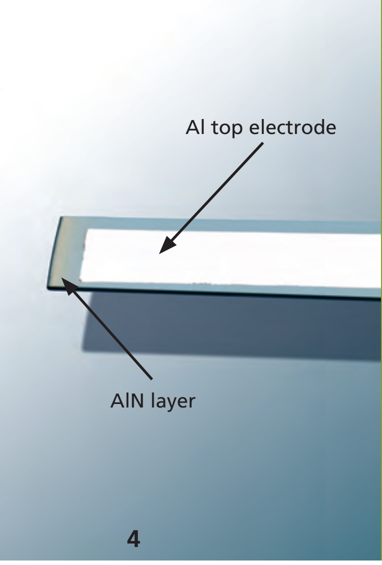
## Introduction

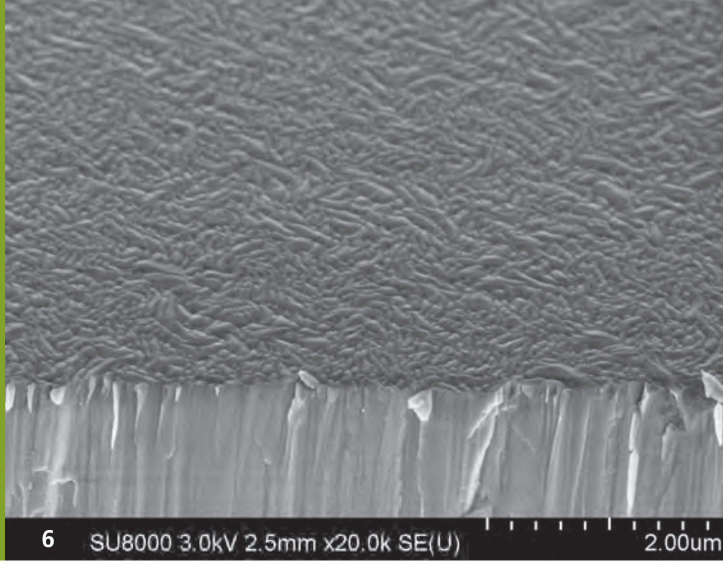
Currently, an increasing demand for autonomous sensors and systems with wireless radio connection and autonomous energy supply can be observed. This is in part due to the strong trend towards continually smaller mobile systems and the increasing market for "wearables".
The energy supply of such systems 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.

## 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 was able to deposit AlN layers with piezo coefficients of more than 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, figure 5). 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.

Moreover, tests for energy harvesting with AlN layers on silicon (Si)-strips were carried out in cooperation with the Dresden University of Technology and the University of Oulu (Finland) (figure 4). The oscillators showed generated powers in case of resonance, which are sufficient to operate low-power electronics (e.g. sensors). 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 30 pC/N at similar coating rates and moderate film stress.

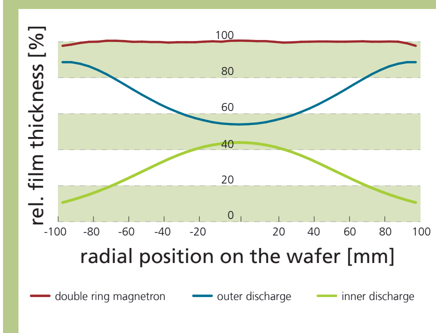
## Energy harvesting demonstrator

Fraunhofer FEP developed a first demonstrator for the presentation of energy harvesting solutions by means of AlN layers (figure 1 and 2). 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 AlScN) is stimulated to oscillate. The silicon cantilever is electrically contacted. The power is calculated by measuring the generated voltage. In resonance the maximum of the generated energy will be achieved.

*7 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 | 30 |
| deposition rate [nm/min] | 100 … 200 | 100 … 200 |
| film stress | customer-specific | |

*8 Coating thickness distribution of DRM 400*




## Services

- application-specific layer depositions of AlN and $Al_xSc_{1-x}N$ (e.g. for energy harvesting)
- customized system development of the harvester
- optimization of materials and coatings for further fields of application (ultrasound generation, resonance filter, actuators)

## Applications

- autonomous on-site energy generation for sensor applications
  - automobile
  - aerospace
  - mechanical engineering
  - monitoring
  - medical technology

*4 AlN layer on Si-substrate as design of Energy Harvester*

*5 Double Ring Magnetron DRM 400*

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