piezoMEMS Platform for various piezo-electric Materials

Fraunhofer ISIT

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Introduction

In the macro world, the use of piezoelectric materials for various sensor and actuator applications is well established. Especially its ability to generate high forces at comparatively low power consumption makes the (inverse) piezoelectric effect extremely attractive for MEMS. However, the integration of piezoelectric materials in form of thin films still remains a challenge.

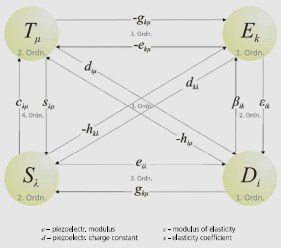
The mere existence of a certain portfolio of piezoelectric materials is however not the only prerequisite for the manufacturability of complex MEMS devices. Below, Fraunhofer ISIT presents its meanwhile 10 years+ experience and capabilities on the integration of piezoelectric layers into MEMS fabrication processes for manufacturing complex devices, *e.g.*, for acoustic, optical and energy harvesting applications. Our aim is to cover the complete development chain including conception, (FEM) simulation, design, prototype manufacturing, characterization and reliability testing. The piezoMEMS module offers AlN, AlScN and PZT with deposition, patterning and characterization technologies all embedded in a 200 mm MEMS fab environment meeting industrial requirements. Together with ISIT's Poly-Si technology module and the (vacuum) wafer level packaging (vWLP) capabilities a variety of innovative high performance piezoMEMS devices are realized.

Design & Conception

Based on the fundamental physics of the piezoelectric effect, the ideas for piezoelectric MEMS devices are realized into drafts considering

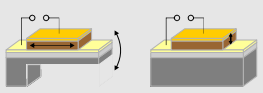
- the available piezoelectric material portfolio
  PZT: non-linear, low driving voltage, highest piezoelectr. coefficients → actuator applications
  AlN: linear, low piezoelectr. coefficients, IC-compatible, low dielectric losses → sensor appl.
  AlScN: linear, intermediate piezoelectr. performance, IC-compatible, low dielectric losses → sensor and actuator applications,
- the applicability of longitudinal or transversal effect,
- the ability to integrate and combine with ISIT's base technologies and other technology platforms,

while making extensive use of device modeling by finite element method simulations.

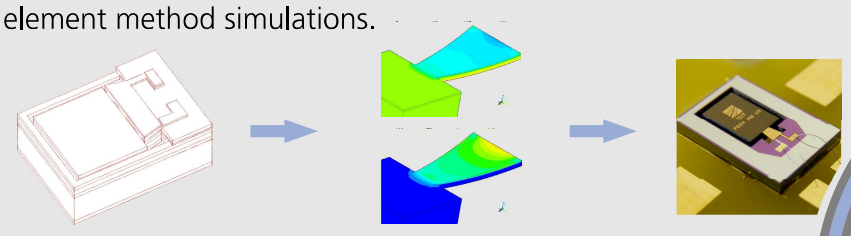


$$S = d \cdot E + s^E \cdot T$$
$$D = d \cdot T + \varepsilon^T \cdot E$$

Scheme for linear electromechanical equations as base for FEM simulation

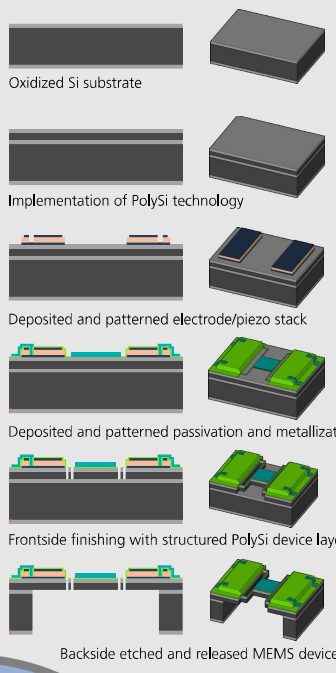


Transversal vs. longitudinal piezoelectric effect



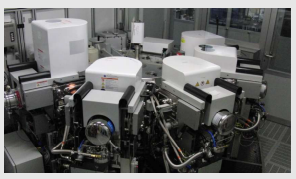
From idea via concept and FEM simulation to the manufactured MEMS device

Process Integration

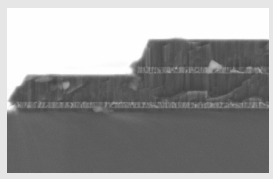


Fabrication processes and process flows are developed to realize the concepts in real devices, executed in a 200 mm MEMS fab environment.

- Tool park for deposition and structuring of piezoelectric thin films:
  Sputter deposition of PZT, AlN, AlScN [1]
  Wet and dry etching for all piezoelectrics
- Integration of additional technology platforms:
  PolySi for precise definition of movable and deformable elastic layer of MEMS device
  (Vacuum) wafer-level packaging (vWLP) to seal and protect devices or integrate additional functionality
- Combination with large portfolio of *base techn.*: e.g. metal and dielectric thin films for passivation and rewiring



One of ISIT's sputter clusters for piezo-electric thin films and electrode materials



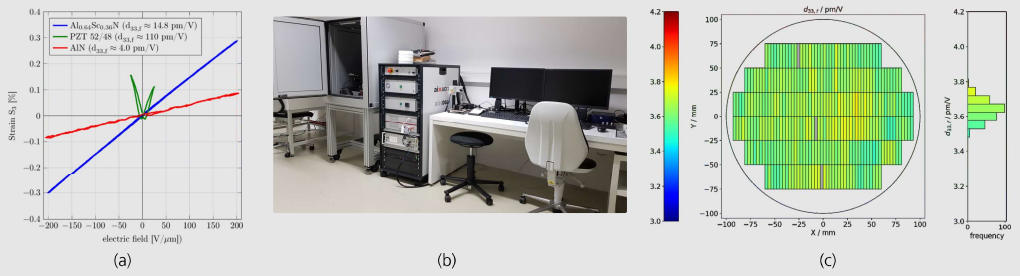
Integrated double layer AlN / electrode stack

piezoMEMS Technology Platform at ISIT

Characterization

With its continuous extension of common process control and device test methods by piezoelectric characterization capabilities, ISIT is able to offer a wide variety of test and characterization setups starting from the piezoelectric thin film up to the piezoMEMS device.

- *Waferlevel characterization* for piezoelectric coefficients as well as ferroelectric and electrical properties of thin films
- *Chiplevel characterization* for MEMS devices by laser doppler vibrometry and application specific test setups
- Access to further *material specific analysis* (XRD, TEM)
- Dedicated work group and capabilities for *Test & Reliability* of MEMS devices



(a) (b) (c)

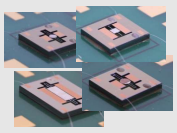
(a) Comparison of ISIT's integrated PZT, AlScN and AlN thin films. (b) Double beam laser interferometer (DBLI) and 4-point-bending setup for direct and precise measurement of piezoelectric coefficients $d_{33,f}$ and $e_{31,f}$, ferroelectric and dielectric thin film properties. (c) $d_{33,f}$ wafer map (AlN).

Applications

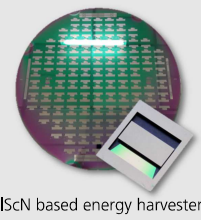
The piezoelectric thin films are implemented in numerous MEMS devices conceived and / or manufactured at Fraunhofer ISIT for a large variety of applications.

Large scaled MEMS scanner based on PZT

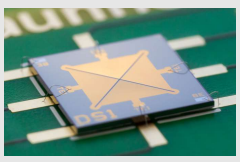
- Micro mirrors for optical scanner application (PZT, AlN, AlScN)
- Acoustic transducers (micro loudspeaker, microphones, ultrasonic transducers) (PZT, AlN, AlScN)
- Physical and biomedical sensors (AlN)
- Energy harvesters (AlN, AlScN)
- MEMS switches (PZT, AlN)



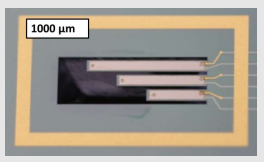
Various designs of MEMS scanners based on PZT [2]



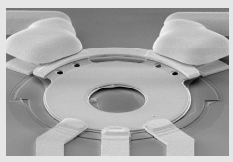
AlScN based energy harvester



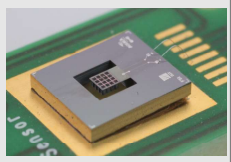
PZT based MEMS micro speaker



Magnetoelectric sensor based on combined magnetostrictive and piezoelectric AlN thin films [3]



PZT actuated MEMS switch



Magnetic field sensitive µEnergy harvester

Funding & References

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[1] S. Fichtner *et al.*, *J. Appl. Phys.* 125 (2019), 114103
[2] S. Gu-Stoppel *et al.*, *TechConnect Briefs* 4 (2016), 87-91
[3] S. Marauska *et al.*, *Sens. Actuators A* 189 (2013), 321-327