Influence of Pressure and Temperature on the Growth and Properties of Pulsed Laser Deposited PZT for MEMS

A. Schatz\textsuperscript{1}, D. Pantel\textsuperscript{1}, and T. Hanemann\textsuperscript{2,3}

\textsuperscript{1} Robert Bosch GmbH, Robert-Bosch-Campus 1, 71272 Renningen, Germany, Corporate Sector Research and Advance Engineering
\textsuperscript{2} University of Freiburg, Department of Microsystems Engineering - IMTEK, Laboratory for Materials Processing, Georges-Köhler-Allee 102, 79110 Freiburg, Germany
\textsuperscript{3} Karlsruhe Institute of Technology, Institute for Applied Materials (IAM), P.O. Box 3640, 76021 Karlsruhe, Germany
Motivation
PZT for MEMS

PZT MEMS on the market

- Silicon Sensing: gyroscope with vibrating ring layout
- Panasonic: gyroscope with tuning fork layout
- poLight: autofocus lens
- Foundries: Rohm, SINTEF, Silex Microsystems AB, X-FAB Semiconductor Foundries AG, ...

Technologically interesting material for MEMS actuators

- High $e_{31,f}$ is needed
- $e_{31,f}$ is dependent on the microstructure*

PZT growth-control is of main interest:
Variation of deposition pressure and temperature influence growth and properties.

* S. Trolier-McKinstry and P. Muralt, J. Electroceram., 12 (2004), pp. 7-17
Introduction

Pulsed Laser Deposition

IR heater: up to 800 °C
(445 ≤ $T_{\text{dep}}$ ≤ 570 °C used for PZT)

Background gas (here: $p_{\text{O}_2}$)
range used: 0.05 to 0.20 mbar

Diverse materials: e.g. PZT, LNO*, SnO$_2$, CuO, ...

Manifold applications: perfect tool for corporate research

* LNO = LaNiO$_3$
Variation of Pressure ($p_{O2}$) Microstructure (SEM)

$T_{dep} = 570 \, ^{\circ}C$

$\rho_{O2} = 0.05 \, \text{mbar}$

$\rho_{O2} = 0.20 \, \text{mbar}$

$\bar{\phi} = 127 \, \text{nm}$

$\bar{\phi} = 64 \, \text{nm}$

The grain sizes and grain boundaries are effected by the deposition pressure.
Variation of Temperature ($T_{dep}$) 
Microstructure (SEM)

$T_{dep} = 445 \, ^\circ C$

$T_{dep} = 510 \, ^\circ C$

$T_{dep} = 570 \, ^\circ C$

$\bar{\phi} = 86 \, \text{nm}$

$\bar{\phi} = 104 \, \text{nm}$

$\bar{\phi} = 127 \, \text{nm}$

$P_{O_2} = 0.05 \, \text{mbar}$
Variation of Pressure / Temperature
Crystalline Phase (XRD)

Pressure and temperature have significant influence on the crystalline phase but no clear trend is visible.

- Pyrochlore peak positions (no peaks visible)
Variation of Pressure / Temperature Atomic Composition (EDX)

The lead content of the film correlates with the microstructure.
Variation of Pressure ($p_{O_2}$) Permittivity

The domain mobility of the film deposited at 0.20 mbar seems to be much higher.
Variation of Temperature ($T_{\text{dep}}$) Permittivity

The mobility of the domains decreases with increasing deposition temperatures.

Extrinsic contribution

$P_{O2} = 0.05 \text{ mbar}$
The microstructure has high effect on the $e_{31,f}$. Not only crystalline phases but also grain boundaries play a major role.

$e_{31,f}(E_3) = -\frac{d\sigma_1}{dE_3}$

Conclusion
PLD settings: high effect on PZT properties

- PZT film properties are dependent on $p_{O2}$ and $T_{dep}$
  - Microstructure: smooth columnar structure $\leftrightarrow$ coarse grain boundaries
  - No clear trend in crystalline phases (XRD)
  - Lead content: higher for higher $p_{O2}$ and lower $T_{dep}$
  - Extrinsic contribution to the permittivity (mobility of the domains dependent on the microstructure)

- Piezoelectric coefficient $e_{31,f}$: no linear correlation to $p_{O2}$ and $T_{dep}$
  - Additional factors (e.g. lead content) besides crystalline phases need to be used as indicator for high $e_{31,f}$
  - Combinations of $p_{O2}$ and $T_{dep}$ with other deposition settings (laser energy, laser spot size, ...) result in even higher -$e_{31,f}$ of >14 C/m² (not shown here)
THANK YOU