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Investigation of the Aging of Micromachined Silicon Actuators

Alex Dommann

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PREFACE

The technological advances of microsystem engineering in the past decade have been truly impressive in both pace of development and number of new applications. Microsystem engineering involves the design, manufacture, and packaging of microelectromechanical systems (MEMS) and peripherals. Applications of Microsystems in the aerospace, automotive, biotechnology, consumer products, defense, environmental protection and safety, healthcare, pharmaceutieal , and telecommunications industries prompted many experts to account for a $82 billion in revenue for the Microsystems and related products in the year 2000.

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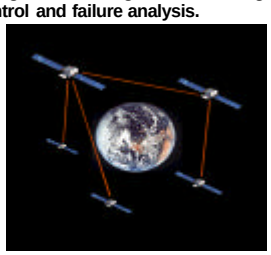
The strong demand for MEMS and Microsystems by a rapidly growing market has generated strong interest in quality control and failure analysis.



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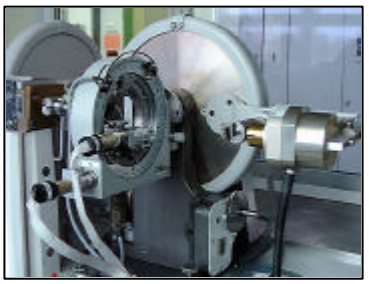
X-Ray Diffraction



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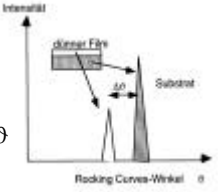
Bragg-Equation $2\,d\sin\vartheta = n\lambda$ $\quad d = \dfrac{\lambda}{2\sin\vartheta}$

$$\Delta d = \frac{\lambda}{2}\left(\frac{-\cos\vartheta}{\sin^2\vartheta}\right)\Delta\vartheta$$

Hook Law : $\boldsymbol{\sigma} = \boldsymbol{\varepsilon}\,\mathbf{E}$ $\quad \sigma = \dfrac{F}{A}$

$$\varepsilon := \frac{\Delta d}{d} \Rightarrow \varepsilon = \left(\frac{-1}{\tan\vartheta}\right)\Delta\vartheta$$



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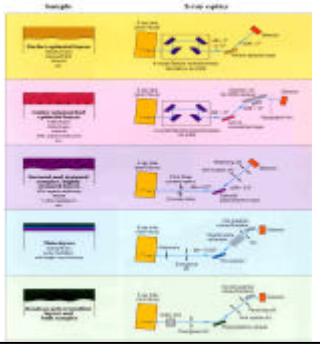
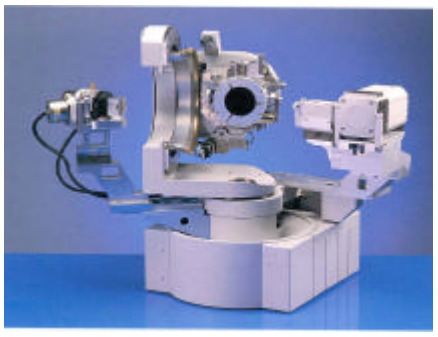
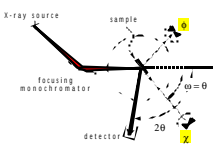




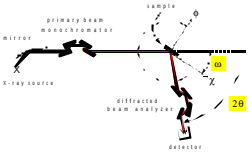
Diffraction geometries

texture diffractometry
· orientation analysis ·

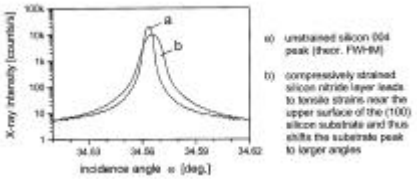


- Bragg reflection fixed (ω, 2θ)
- sample orientation changed (χ,φ)

high-resolution diffractometry
· metric determination ·

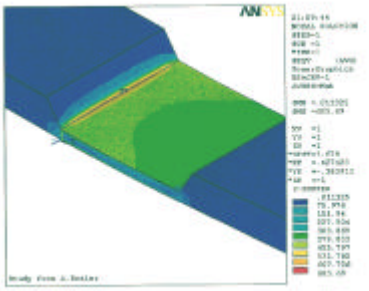


sample orientation fixed (χ,φ)
Bragg peak scanned (ω, 2θ)

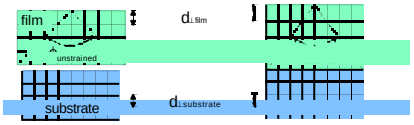


a) unstrained silicon 004 peak (theor. FWHM)

b) compressively strained silicon nitride layer leads to tensile strains near the upper surface of the (100) silicon substrate and thus shifts the substrate peak to larger angles



Exploring the strain situation with thin films



$d_{\perp film} = d_{\perp film}$

$d_{\perp film,strained} \neq d_{\perp film,strained}$

$\phi_{strained} \neq \phi_{unstrained}$

$d_{film} = d_{substrate}$

$d_{\perp substrate} = d_{\perp substrate}$

$d_{\perp substrate} \approx d_{\perp substrate}$

completely unstrained ⇔ pseudomorphically strained
(assuming a cubic metric)

Typically a strong argument to use monocrystalline material and especially silicon is its potential resistance against aging. Aging of a crystal can be documented as a change of the strain and by simulation the strain profile. High Resolution X-ray Diffraction (HRXRD), X-ray standing wave method (XSW) and reciprocal space mapping (RSM) in addition permits to characterize the amount of crystalline defects introduced by cycling and by manufacturing MEMS devices.

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The starting point for our investigations was the observed fact of a hysteresis of the bimorphous actuator, designed as optical deflection system for ophtalmological applications. The beam deflection angle of the bimorphous beam was measured as a function of the input power. Cycling the activation ended in a shift of the zero point. Repeating the process ended in a shift in the same direction, but to a lower amount. While applying no power during one hour, the zero shifted backwards towards the old origin. Thus some relaxation has taken place. With a maximum input power of less than 100 mW no such hysteresis effects were observed.

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SEM photograph of the chip with different bimorphous actuators. The HRXRD measurements were executed on the middle plate of the fourfold symmetrical structure in the middle of the photograph.

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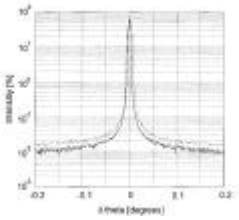

Comparison of the symmetric X-ray rocking curves of the (004) reflection from a (001) cut Si wafer before and after oxidation

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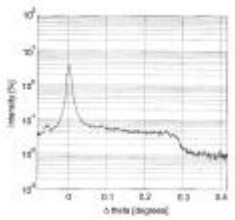

Symmetric x-ray rocking curves of the (004) reflection from a (001) cut Si chip with a bimorphous actuator.

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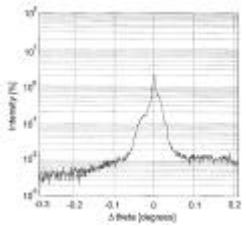

Symmetric x-ray rocking curves of the (004) reflection from a (001) cut Si wafer. The measurements were executed on the same structure after one week of operation.

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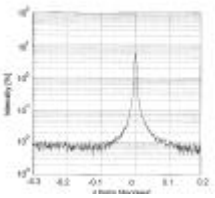
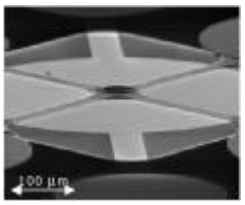
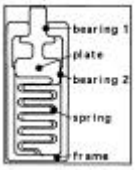
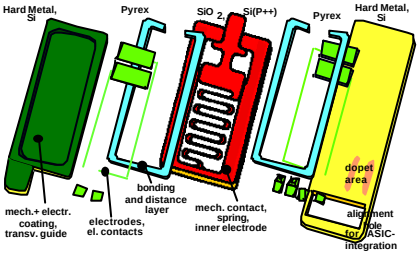


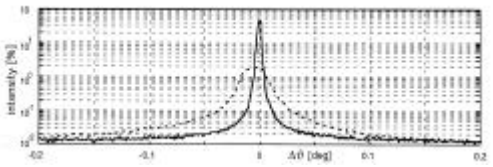
Symmetric x-ray rocking curves of the (004) reflection from a (001) cut Si wafer. The measurements were done on the same structure after removing the aluminium.



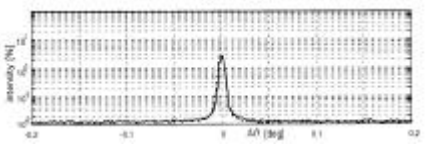
BEHAVIOUR OF A SILICON SPRING FABRICATED BY WIRE ELECTRO DISCHARGE MACHINING.





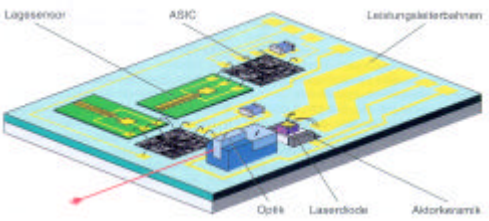


Solid line: symmetric x-ray rocking curves of the (004) reflection from a (001) cut Si chip. Dashed line: symmetric x-ray rocking curves of the (004) reflection for this chip after WEDM.



Symmetric X-ray rocking curves of the (004) reflection from a (001) cut Si wafer. The measurements were executed on the same structure after 3 million of cycles.

Life Time



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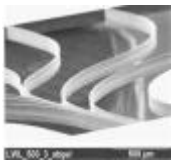
Wave Guide for Intersatellite Link



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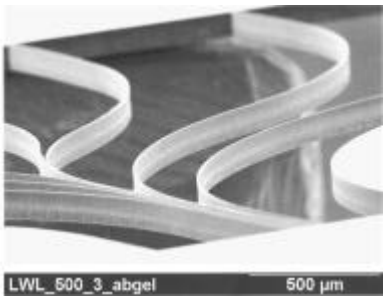

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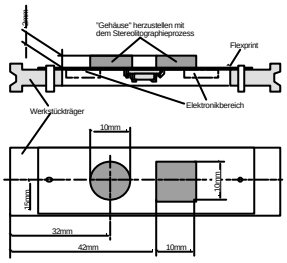
Packaging



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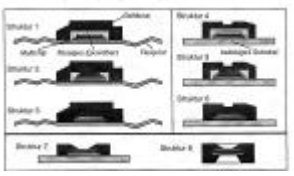

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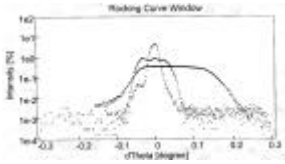

Symmetric x-ray rocking curves of the (004) reflection from a (001) Si chip after production (x), after molding (+) and encapsulated with a new polymer (^) .

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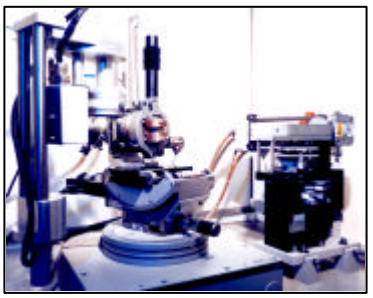

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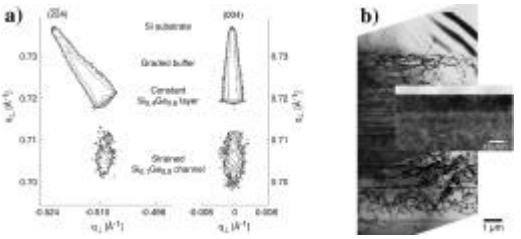
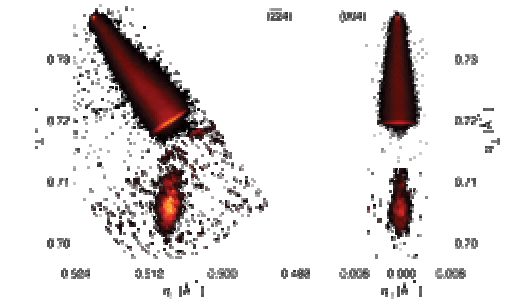
Structural quality





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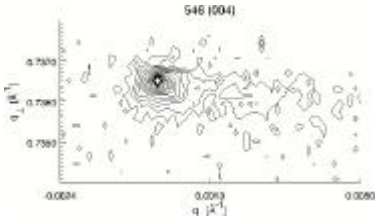

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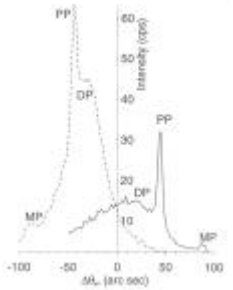

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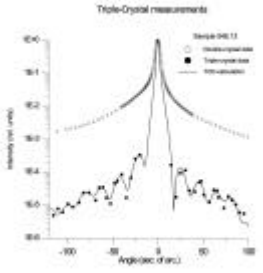

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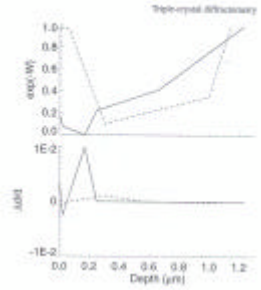

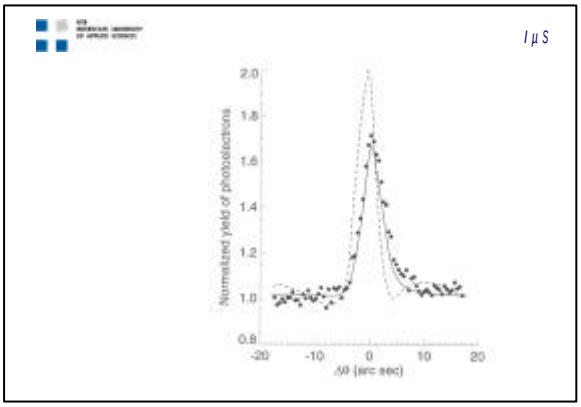

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