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Combining Silicon-MEMS and Direct LIGA for Future MEMS Applications in Space

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Combining Silicon-MEMS and Direct LIGA

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Abstract

MEMS devices based on silicon process technology are state of the art for many applications and the technology is readily available as a foundry service. In both Silicon On Insulator and polysilicon processes it is possible to produce typical MEMS features such as electrical drives and readouts, elastic and friction bearings and optical mirrors. Optical mirrors are always produced horizontally and require a metal deposited on a mirror quality semiconductor or insulator surface and are usually sensitive to bending with changing temperature due to difference in the coefficient of thermal expansion. Great efforts have been put into the possibility to set up vertical mirrors in polysilicon devices by rearranging mirrors that were horizontally produced. Devices produced that way remain complicated and fragile and have a low package density.

With a LIGA process using synchrotron x-rays on the other hand, it is possible to produce monolithic devices with vertical sidewalls of mirror quality. These are electrodeposited into structures produced lithographically. Usually gold or nickel is used as a metal. As it is difficult to integrate other MEMS features as drives and bearings into LIGA parts the combination of silicon MEMS and metal LIGA represents the potential to create a new class of devices with both vertical and horizontal mirrors in a dense package.

As gold has a density that is more than eight times larger than that of silicon, it can be of advantage to use it in MEMS devices that require a large mass. Especially if the large density has to be combined with extreme dimensional accuracy like in a MEMS reaction wheel the combination of gold LIGA and silicon MEMS could enable completely new devices

We will present the status of our work to develop the technology to combine these processes. The work includes dealing with issues of integrating both technologies such as the creation of an appropriate plating base and mask alignment during lithography. It also comprises defining a first set of design rules and defining a technology demonstrator.

Combining Silicon-MEMS and Direct LIGA

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- Introduction
- (Direct) LIGA at Karlsruhe
- Available Foundry services
- Combination
- Applications
- Issues
- Next steps

Combining Silicon-MEMS and Direct LIGA

Introduction

LusoSpace is a technology manufacturer of advanced and innovative space technology focused on:

- AOCS hardware (Attitude and Orbit Control System)
- GNC software (Guidance, Navigation and Control)
- Components Qualification
- Laser Systems & Optoelectronics
- Space Electronics

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Introduction

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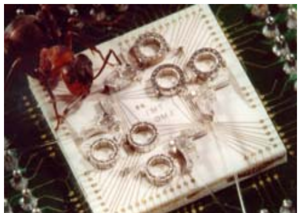
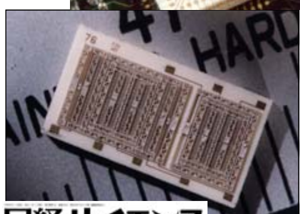
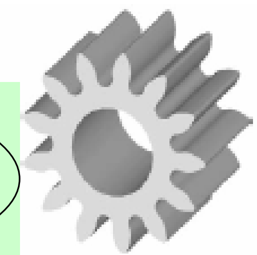
Microwork stands for a new level of maturity of LIGA-technology







- X-ray Be-Masks
- Second Source

- Reliability
- Repeatability
- Q-Standards
- Transfer to SME

Automation for

- Cost-Reduction
- Increased Throughput

- MODULIGA
- LIGA 4H
- FELIG

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1986 | bis 1998 | Sep 05 | 2008

Haute Couture

Prêt â porter

LIGA-Roadmap with spin-off from FZK

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Introduction

Combining Silicon MEMS and LIGA combines the best of two worlds:

Si-MEMS stands for versatility because of:

- Easily integrated drives and sensors
- the wide range of processes and materials that can be used
- simple wafer and die level handling
- Integrated CMOS
- Easily integrated drives and sensors

LIGA gives

- The highest available aspect ratios for structures and gaps
- Mirror quality sidewalls
- Metals with unique mechanical and electrical properties

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Direct LIGA at Karlsruhe

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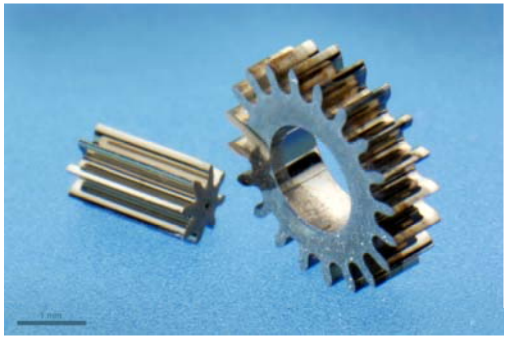
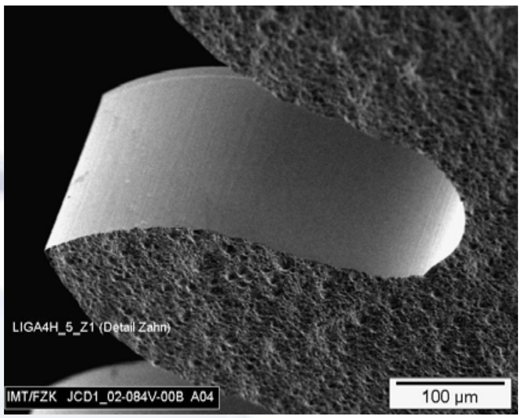
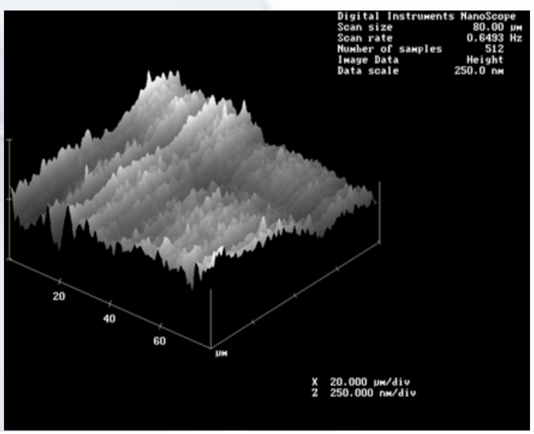






Poperties of x-ray-LIGA structures

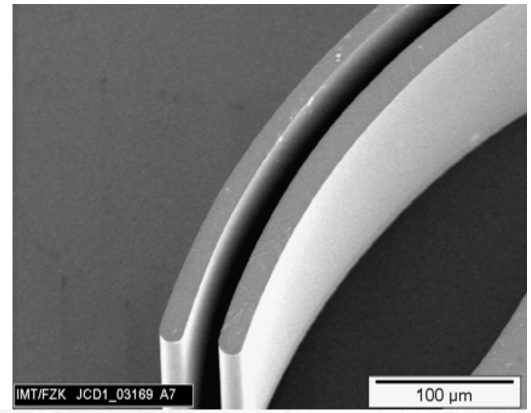
Any lateral geometry

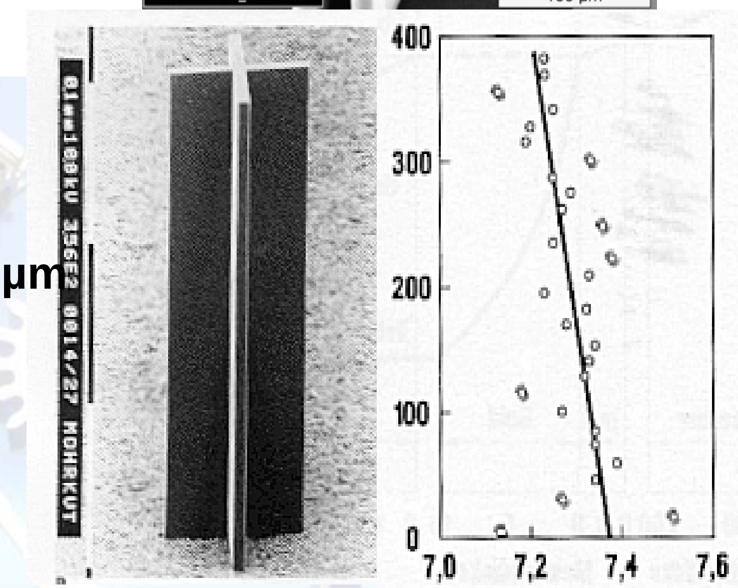
Roughness of sidewall- Ra~30nm

Verticality
0.1µm/100µm (PMMA)
0.3µm/100µm (metal)

Height range 10 bis 2000µm
Height control +-10µm

Available metals:
Ni, NiCo, Au, hard Au





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Direct LIGA at Karlsruhe

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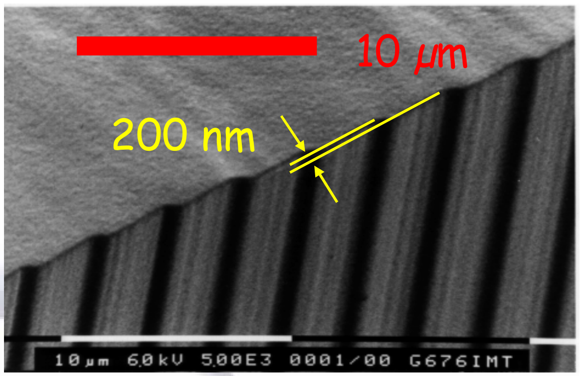
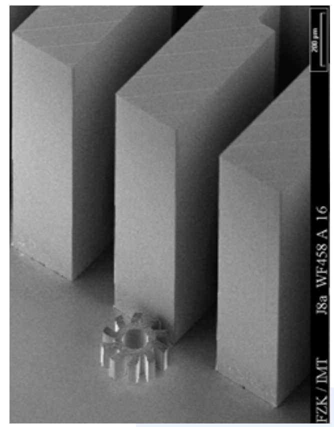
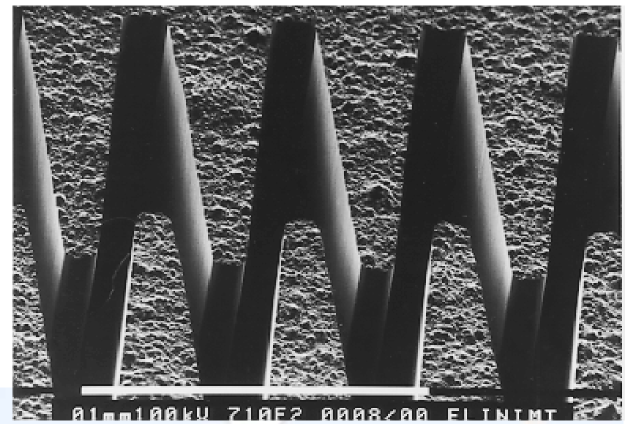
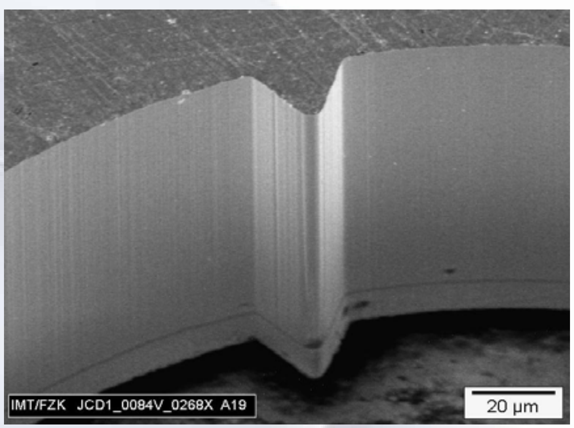
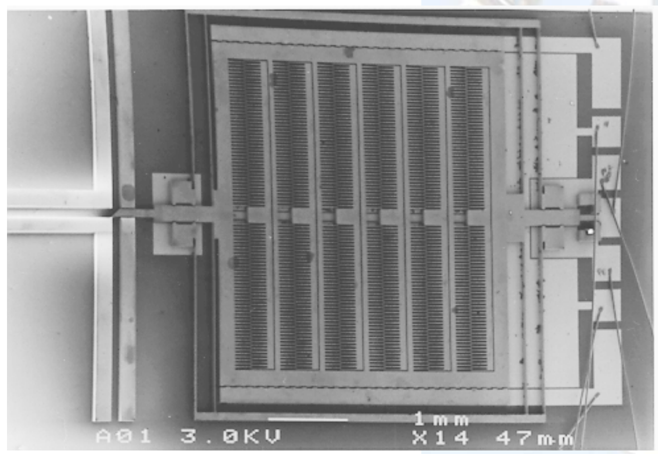


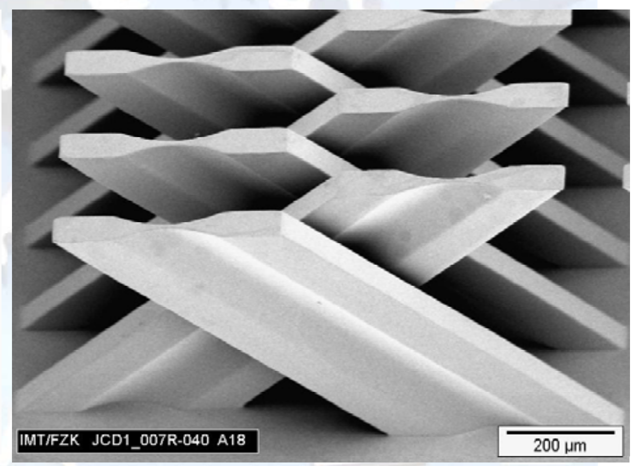
thickness of resist: 400 µm











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Direct LIGA at Karlsruhe

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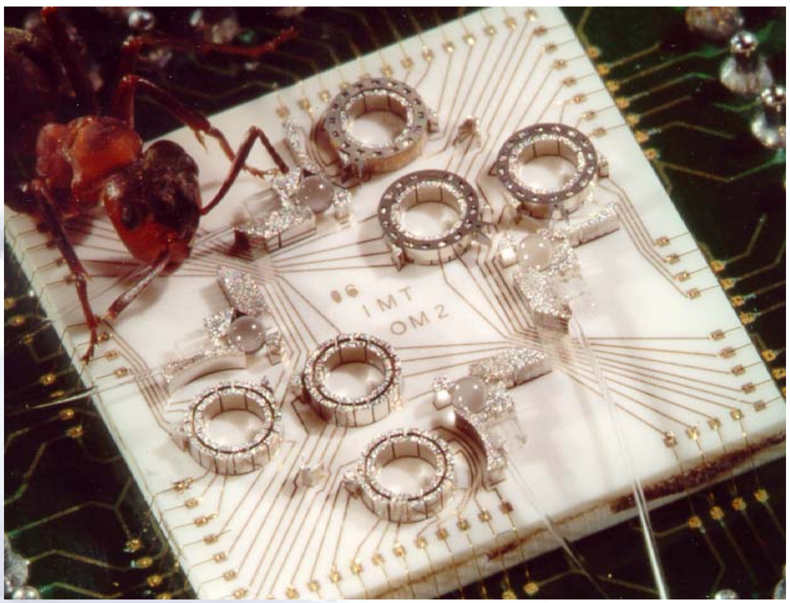

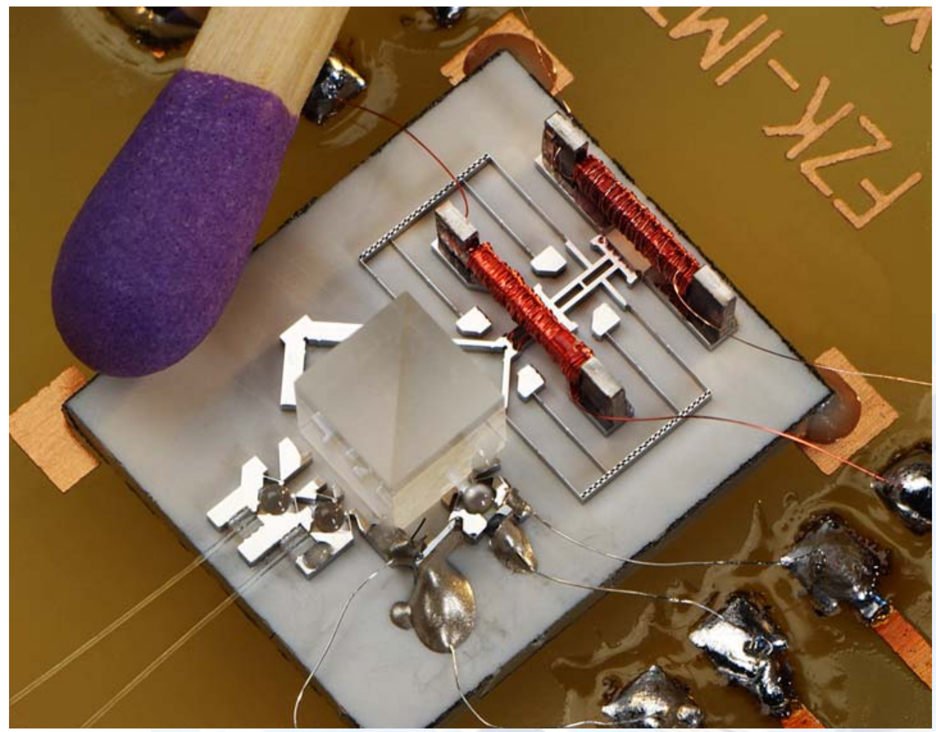

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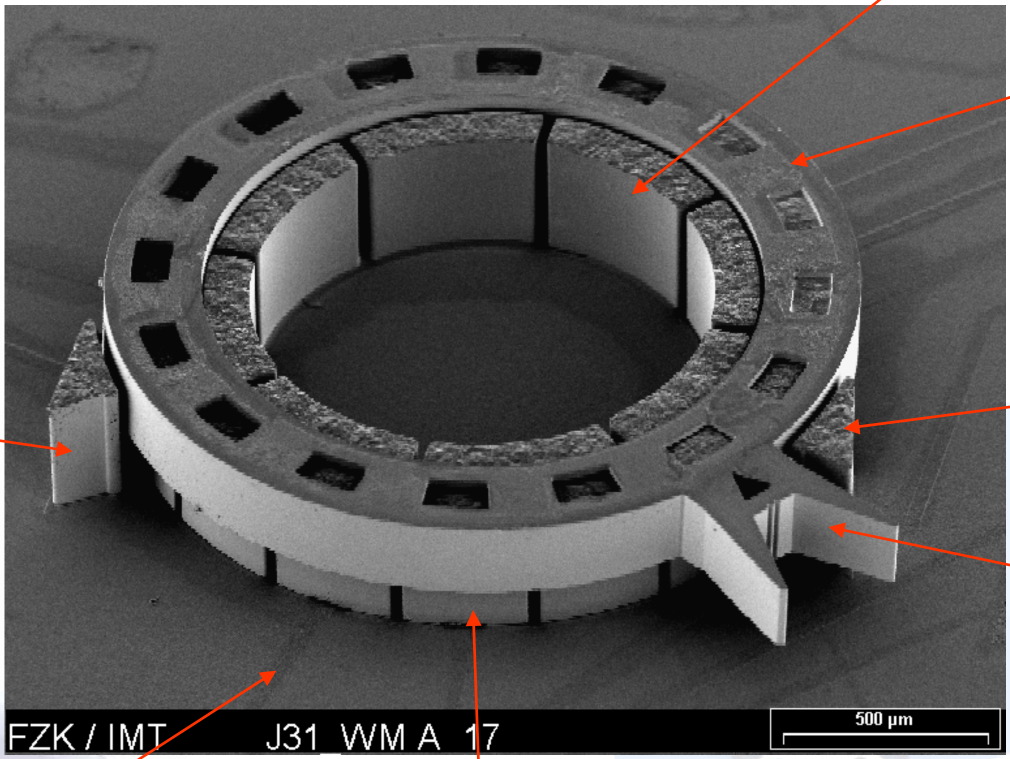
Direct LIGA at Karlsruhe

LIGA-Wobble-Motor



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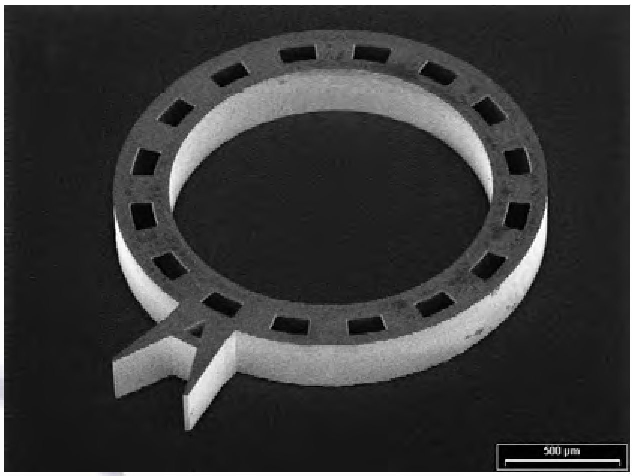
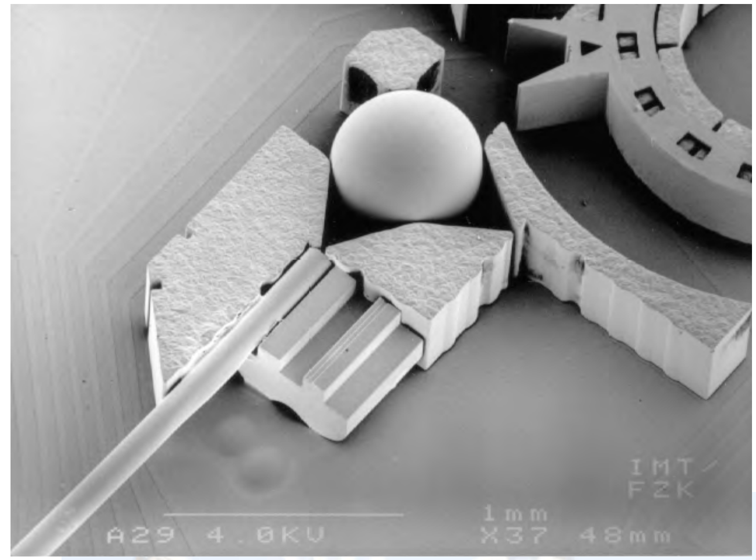
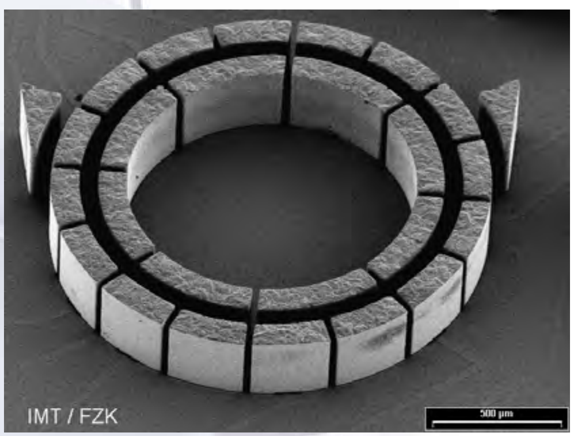
Direct LIGA at Karlsruhe







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Direct LIGA at Karlsruhe

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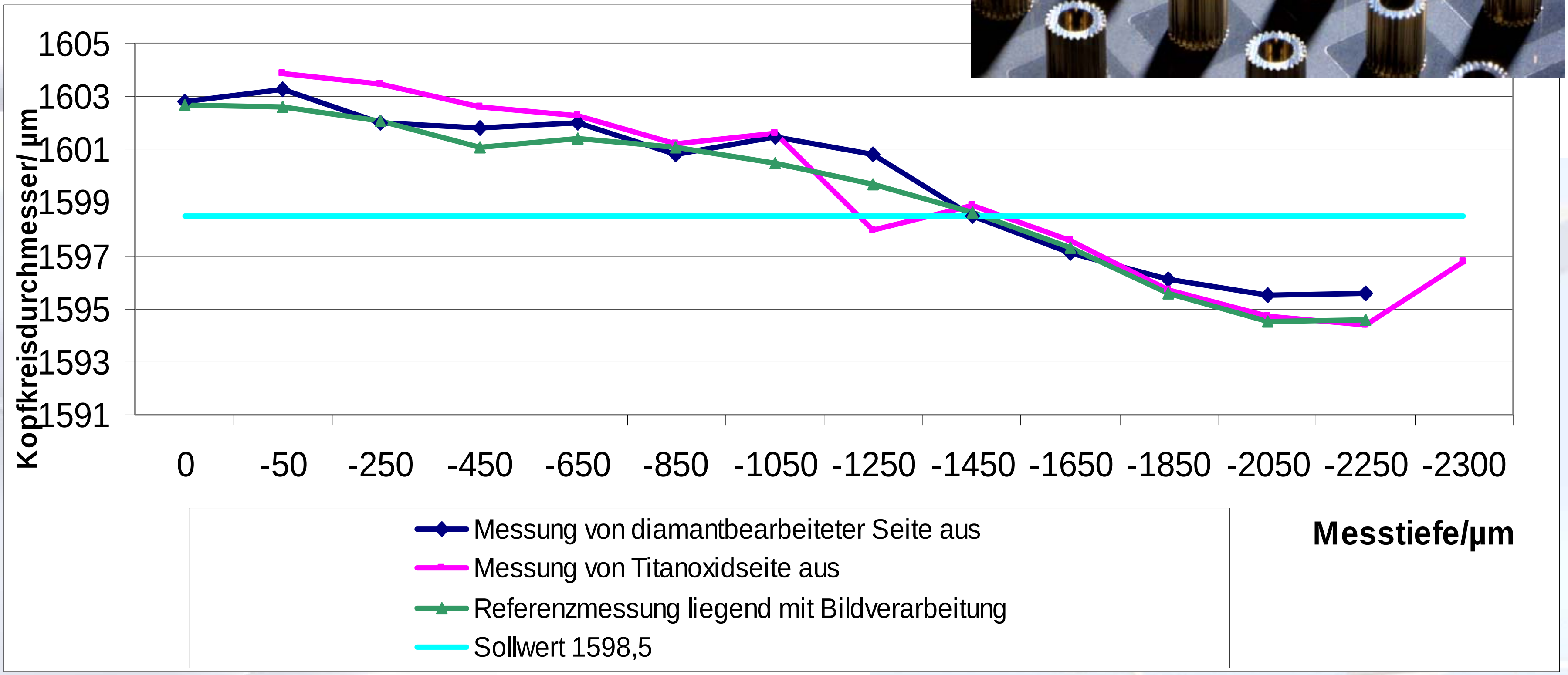
Excellent sidewall verticallity

Change of diameter less than 7µm over 2.3mm

→ 0.33µm/100µm



Combining Silicon-MEMS and Direct LIGA

Available Foundry services

An increasing number of European foundries offers MEMS services, most of them a poly-Si surface micromachining and a SOI bulk micromachining process:

Colibys
Microfab,
X-fab,
Tronic,
STMicrosystems,
Silex,
MEMScap

MEMScap offers as a unique feature a shared wafer program for both p-Si MEMS and SOI MEMS. We used their process flow and design rule as a baseline.

Combining Silicon-MEMS and Direct LIGA

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How to combine LIGA with Si-MEMS

- Hand assembly
  - State of the art, examples: gears, watch parts,..
- On wafer/on die processing
  - Resist is applied to Si-MEMS in intermediate or final state
  - Exposure, development electroplating and stripping are performed on device
- Wafer/die transfer
  - Resist is applied, exposed developed and electroplated on carrier substrate
  - Structures are transferred as a whole from carrier wafer or as resist/structure slice to the Si-MEMS part

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How to combine LIGA with Si-MEMS

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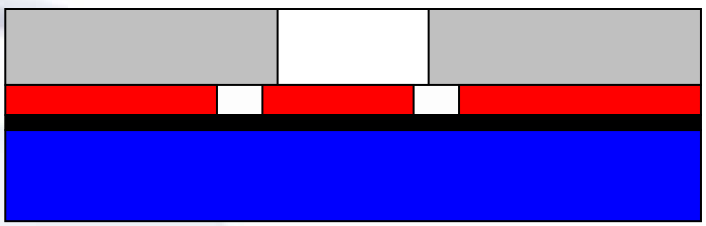
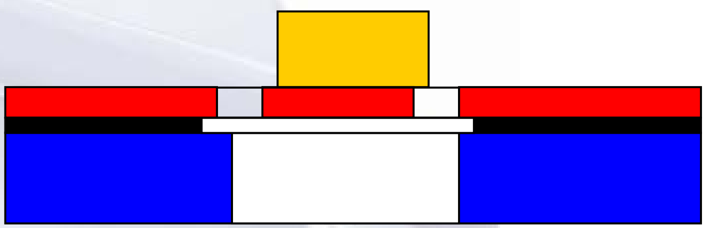
Starting wafer patterned but unreleased,
Perhaps backetched

Application of resist, exposure

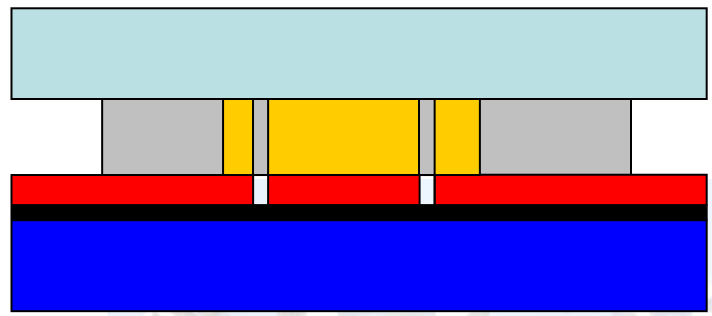


Electroplating, stripping

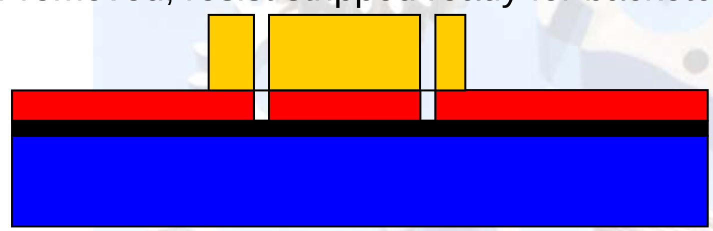


Extra carrier, coated, exposed developed

Electroplating, planarization, bonding to patterned wafer



Carrier removed, resist stripped ready for backetch and release



Si   Si SiO_2 Au   Resist   Carrier

Combining Silicon-MEMS and Direct LIGA

Applications

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- Vertical optical elements
  - Single mirror
  - rooftop mirror
  - Cornercube mirror
  - Focusing mirror
  - Wavefront dividing beamsplitters
  - Reflective gratings
- Drives
- Suspensions
- Larger probe mass devices
  - Gyroscopes
  - Reaction wheels

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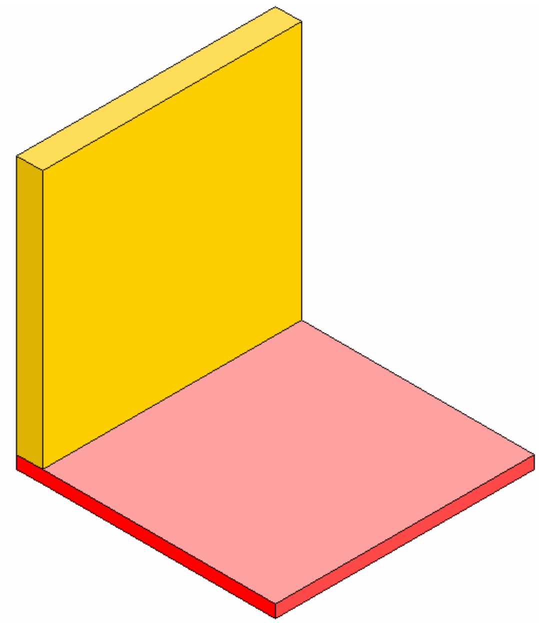

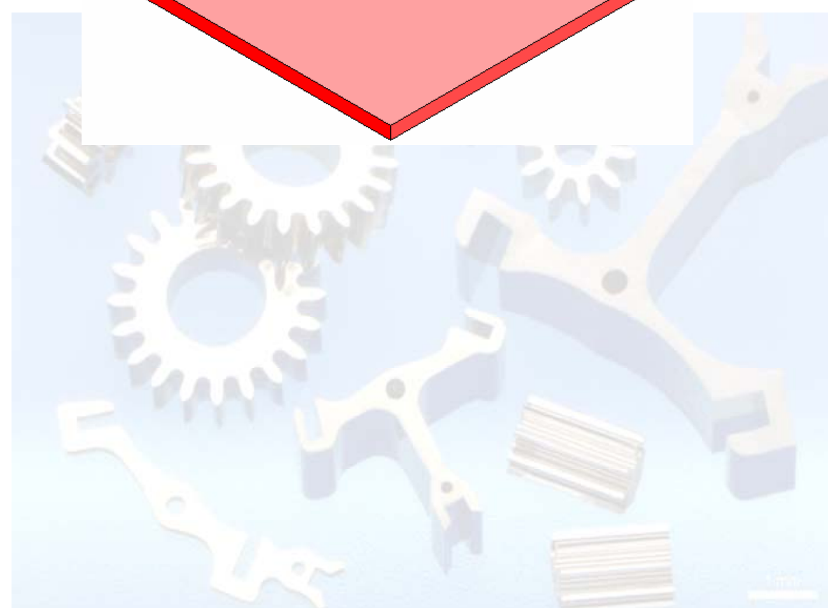

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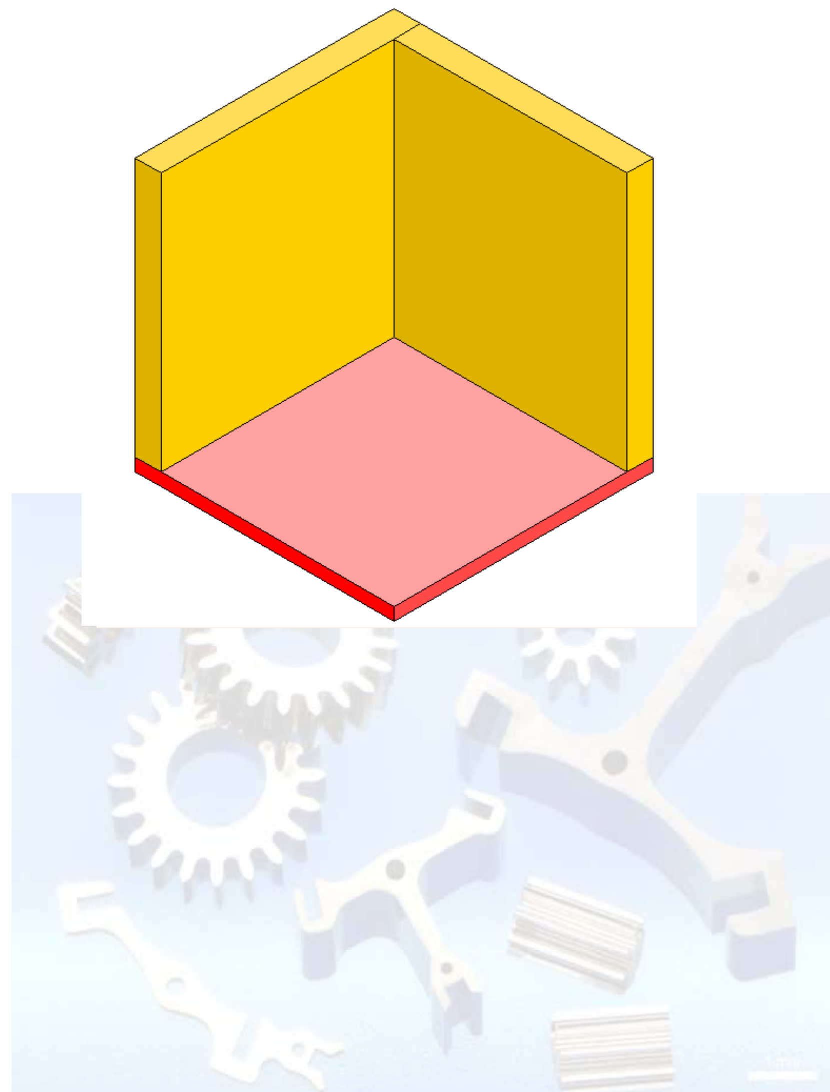

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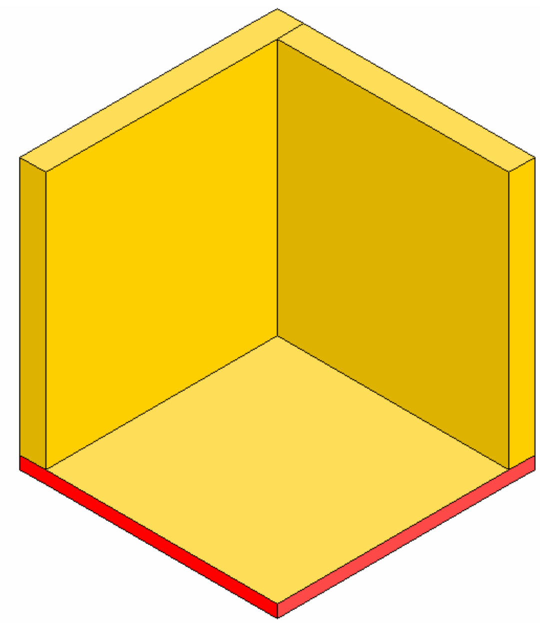

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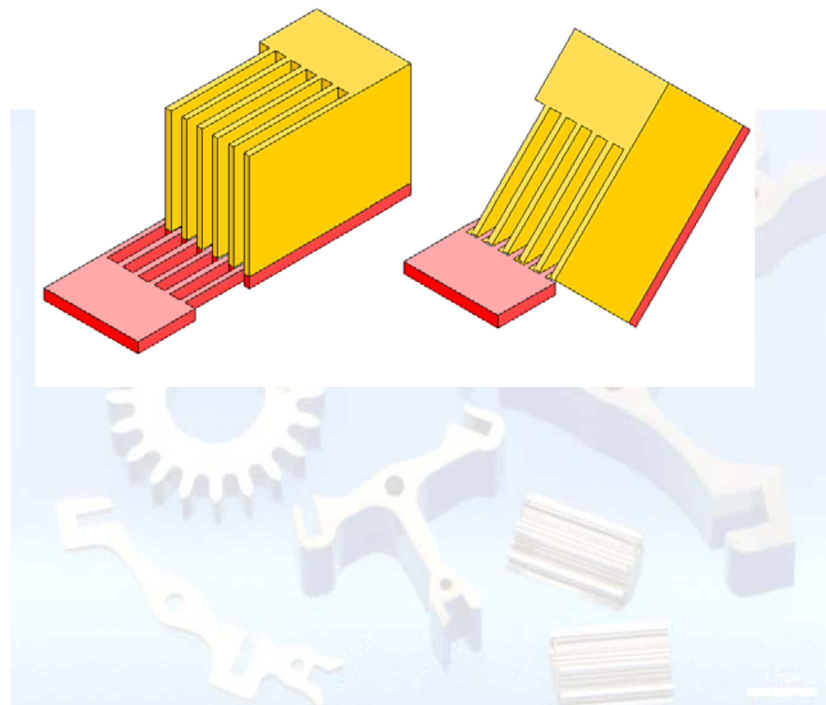

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Applications

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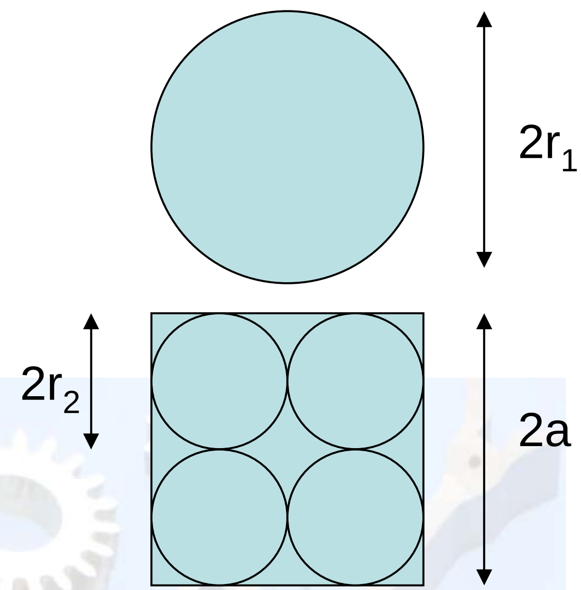
Reaction wheels: Simplified governing equations:

Momentum of Inertia:

$$J=1/2*m*r^2=1/2*\pi*\rho*d*r^4$$

For an array of n^2

$$J_{total}=1/n^2*\pi*\rho*d*a^4$$



$r_2=a/n$

Angular momentum $L=J*\omega$

Stored energy $T=1/2*J*\omega^2$

Everything speaks for large ρ,d and r

Open issue: friction losses (ω^x , bearing requirements (d/r)

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Applications

Reaction wheel: Momentum availability vs demand

Potential sample parameters

<u>*Configuration #1*</u>*:*

100 µm diameter, *2 µm* thick Polysilicon + ***0,5 µm*** thick Nickel

Square matrix of ***1***, ***100*** and ***2 500*** elements

Overall device size a of ***0.2***, ***2.0*** and ***10 mm***

<u>*Configuration #2*</u>*:*

500 µm diameter, *2 µm* thick Polysilicon + ***100 µm*** thick Nickel

Square matrix of ***1***, ***25*** and ***100*** elements

Overall device size of ***1.0***, ***5.0*** and ***10 mm***

<u>*Configuration #3*</u>*:*

1 000 µm diameter, *2 µm* thick Poly-Si + ***500 µm*** thick Nickel

Square matrix of ***1***, ***25*** and ***625*** elements

Overall device size of ***1.0***, ***5.0*** and ***25 mm***

Potential mission parameters

Large-Sat: ***4 m / 2000 Kg*** *Medium-Sat*: ***3 m / 750 Kg***

Mini-Sat: ***2 m / 300 Kg***

Micro-Sat: ***0,6 m/ 50 Kg*** *Nano-Sat*: ***0,25 m/ 5 Kg***

Pico-Sat: ***0,1 m/ 0,5 Kg*** *Femto-Sat*: ***0,05 m/ 0,1 Kg***

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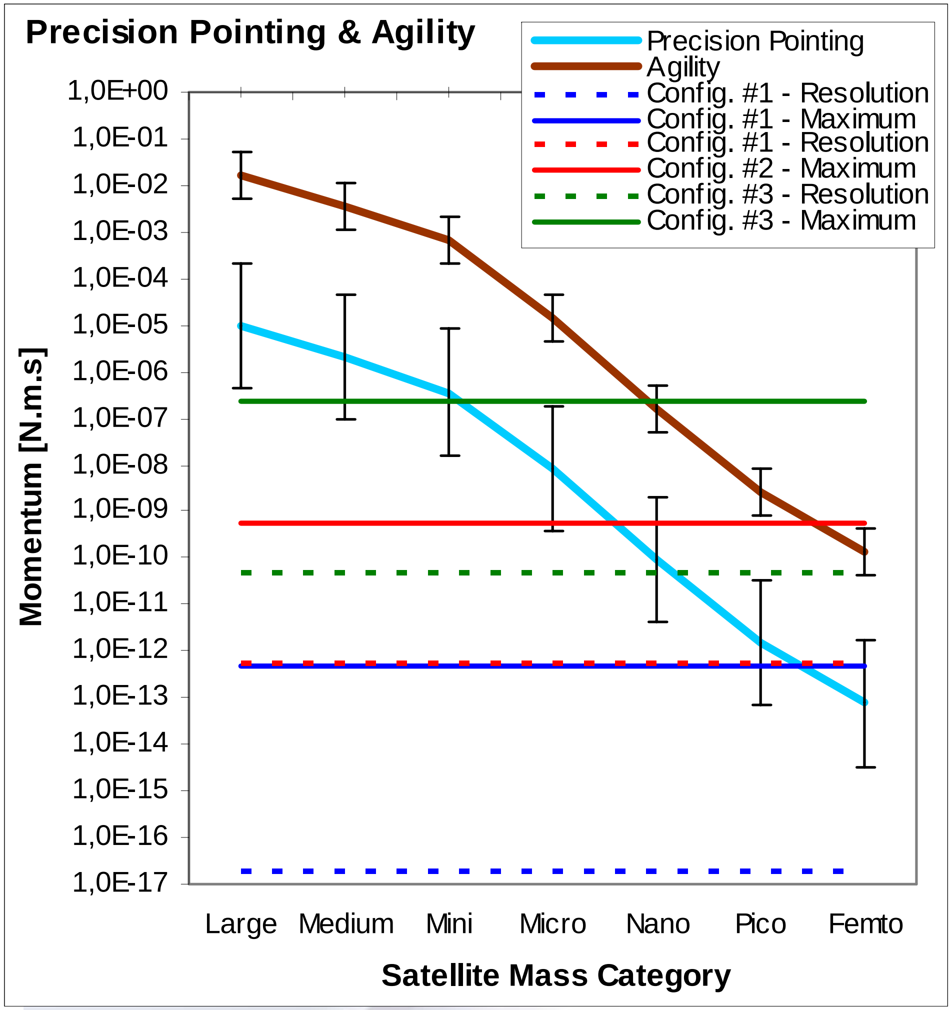
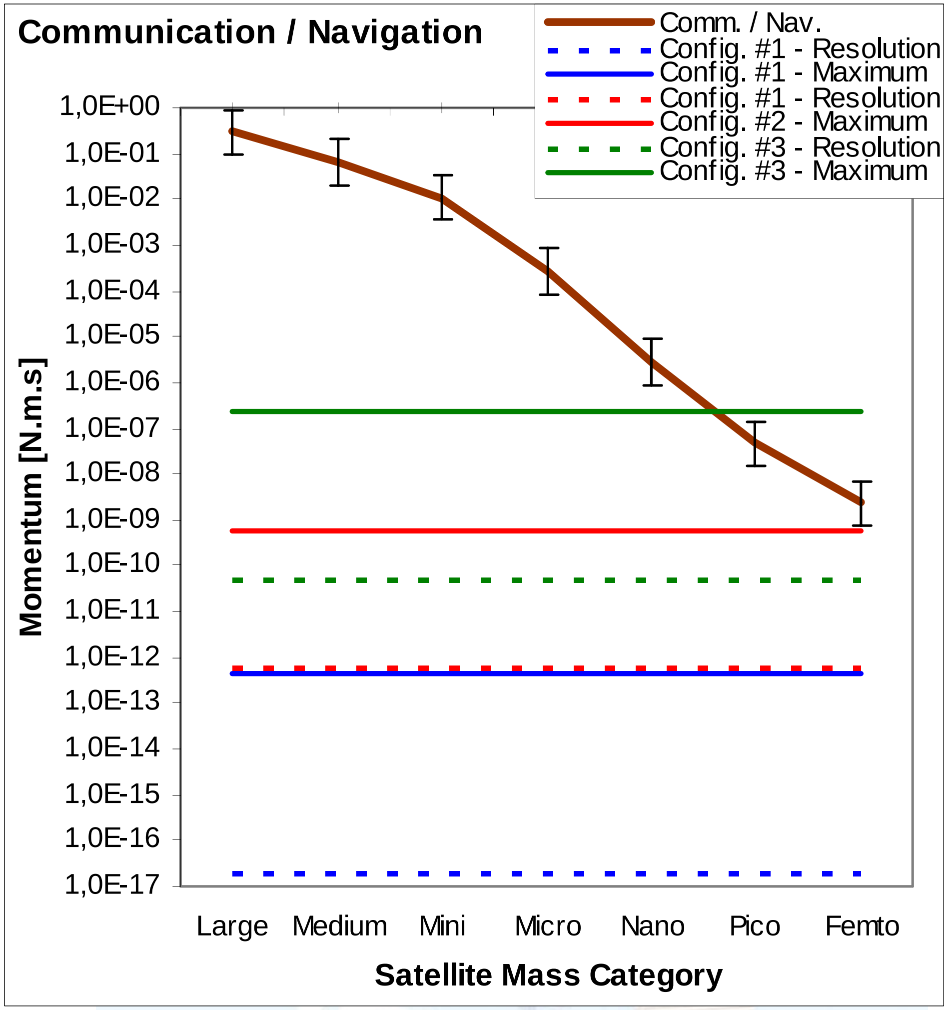
Applications

Reaction wheel: Momentum availability vs demand





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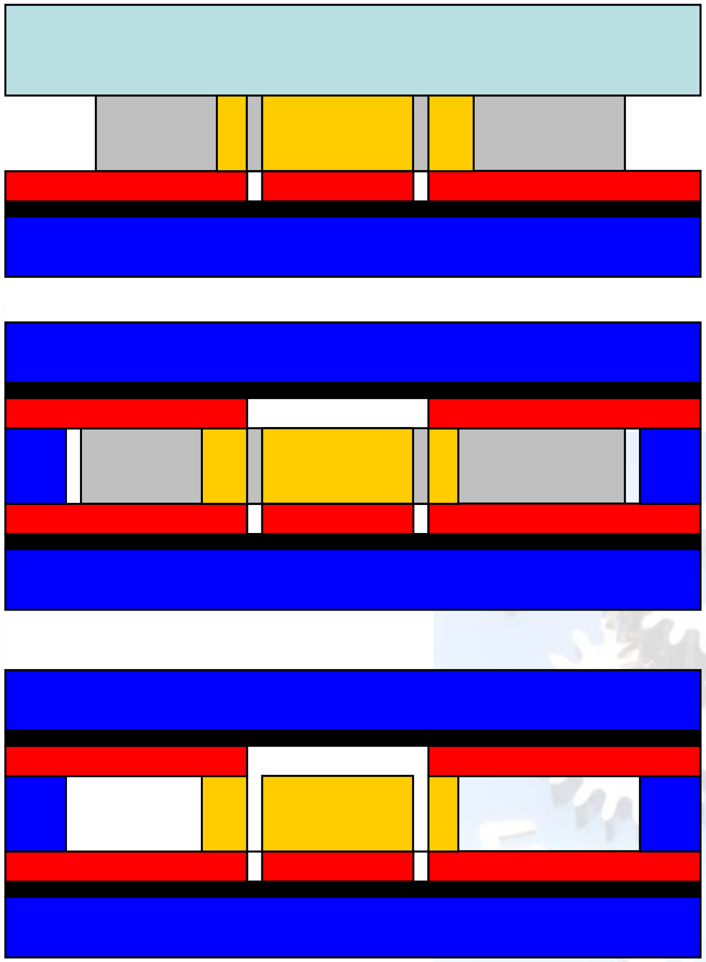
Applications

Reaction wheel process: die transfer/wafer bonding

Advantages:
•Full in plane accuracy
•High wafer-wafer alignment accuracy
,



Problems:
•Bearing
-Friction
-Gas
-Magnetic
-Ball
•Bonding

Si Si SiO_2 Au Resist Carrier

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Issues and potential solutions

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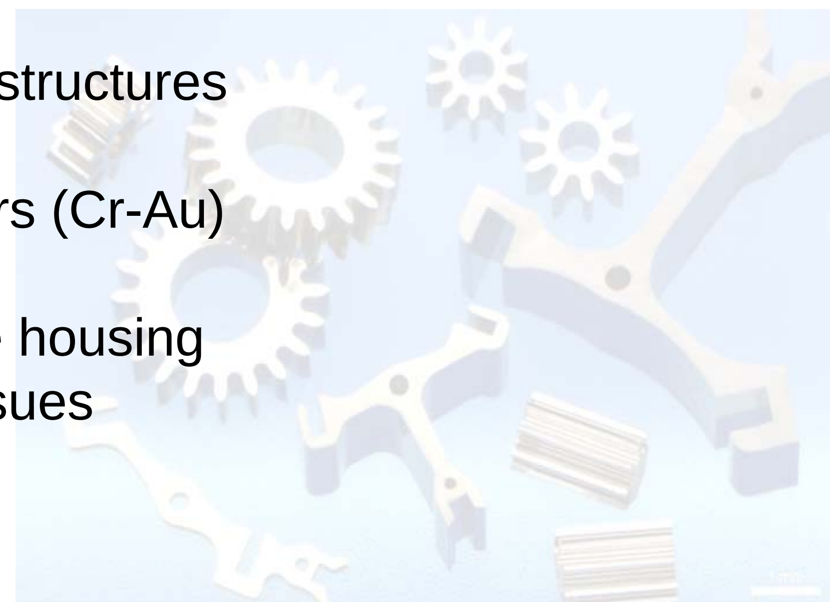
- Plating base
  - Doped Si,
  - Cr, Au
- Alignment
  - wafer level
  - die to carrier
- X-ray dose on CMOS
- CTE stress
  - Stress relieve structures
- Delamination
  - Adhesion layers (Cr-Au)
  - Anchoring
  - Press fit inside housing
- Other reliability issues



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Issues and potential solutions

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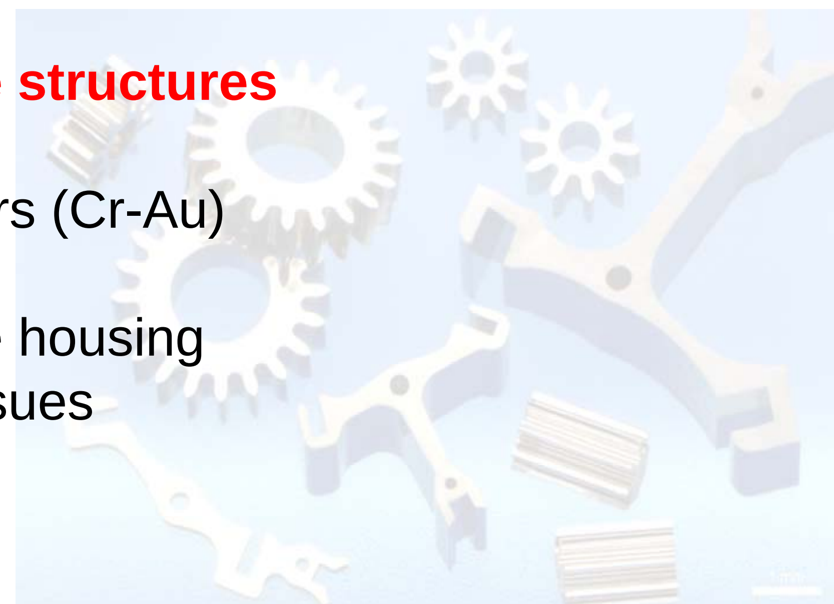

Combining Silicon-MEMS and Direct LIGA

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Next steps

- Decide on foundry for on wafer processing
- Fix process flow
- Establish Layout for:
  - Mirrors
  - Standard comb drives
  - Vertical combined comb drives
  - Other devices
- Run process and analyze results

- Goal: definition of a standardized process with design rules and standard features

- Find partners for wafer/die transfer process