Examples of CMP Processes for the Manufacturing of MEMS Devices

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- poly-Si angular rate sensor
- infrared digital micro mirror array
- capacitive RF-MEMS switch

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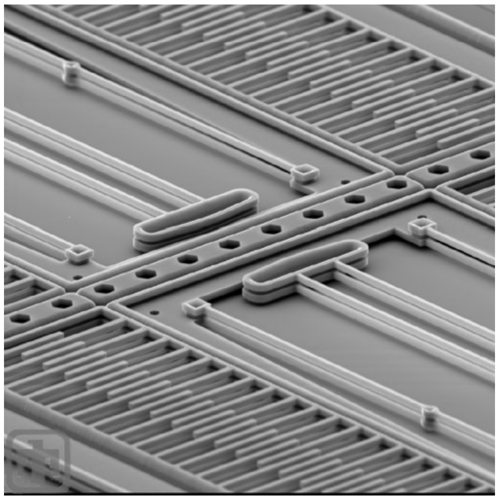
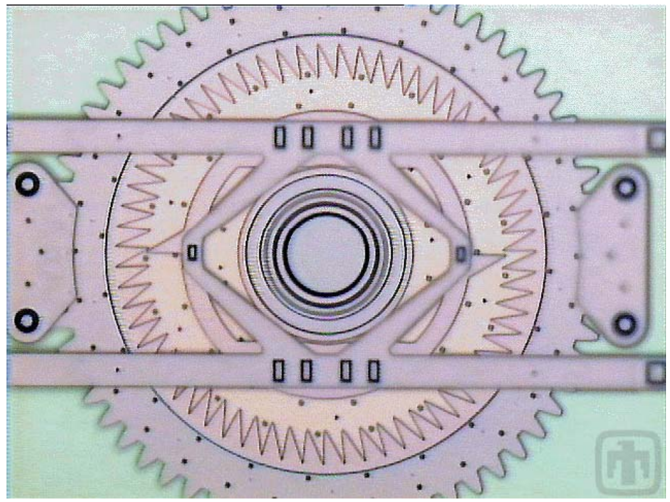
Summary

Pioneering Work by Sandia (1995)

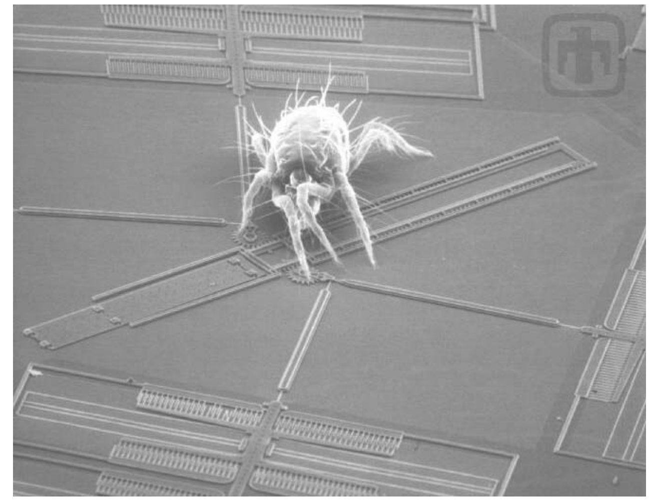
Examples from Sandia's MEMS gallery



comb drive
3 layer poly-Si



indexing motor



„bugs on devices"
spider mite on mirror assembly

Courtesy Sandia National Laboratories. More pictures and movies (!) : www.sandia.mems.gov

Micro-Electro Mechanical Systems (MEMS)

products and markets

MEMS applications and products

Automotive	pressure & air flow sensors, accelerometers, gyroscopes
Aeronautics	pressure sensors, gyroscopes
Consumer	ink jet heads, inertial MEMS, DLPs, Si microphones
Defense	inertial MEMS (for munitions guidance)
Industrial	pressure sensors, liquid flow sensors
Medical & Life Sciences	microfluidics for drug delivery or diagnostics
Telecom	RF-MEMS, micro relays

(Source: Yole Développement market research)

Micro-Electro Mechanical Systems (MEMS)
products and markets

MEMS market outlook

Year	Market (chip level)	Units	E&M Market	(Chemicals)
2006	US$ 6.5 B	1,700 M		
2007	US$ 7.0 B	2,100 M		125 M
2008	US$ 7.8 B	2,600 M		
2009	US$ 8.7 B	3,200 M		
2010	US$ 9.7 B	4,300 M		
2011	US$ 11.3 B	5,800 M		
2012	US$ 13.9 B	6,700 M	> US$ 1 B	228 M

(Source: Yole Développement market research)

Microelectronic vs. MEMS

comparison of requirements affecting CMP

MEMS specifics:

Larger structures	1 µm – 1 mm
Thicker layers	1 – 100 µm
Relaxed planarity requirements	exception: opto-MEMS
Additional materials	metals, polymers, ceramics
Smaller substrates	100-150mm, change to 200 mm
Other substrates than Si	glass, ceramic, metal, polymer
Reduced cleanliness requirements	exception: wafer bonding
Reduced defect requirements	roughness, scratches
Production	smaller unit numbers

CMP in MEMS Production

who is already using CMP ?

Only a few mass products are manufactured using CMP:

Accelerometers, gyros	poly-Si CMP	e.g. Bosch
DLPs, micromirror arrays	oxide planarization	e.g. Texas Instruments
Hard disk drives R/W heads	Ni, Fe, Cr polishing	e.g. Seagate

...

→ CMP is not yet anchored in the heads of MEMS development engineers

→ Versatility of CMP processes has to be demonstrated and published

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Examples of MEMS fabrication using CMP

case studies

- poly-Si angular rate sensor
- infrared digital micro mirror array
- capacitive RF-MEMS switch

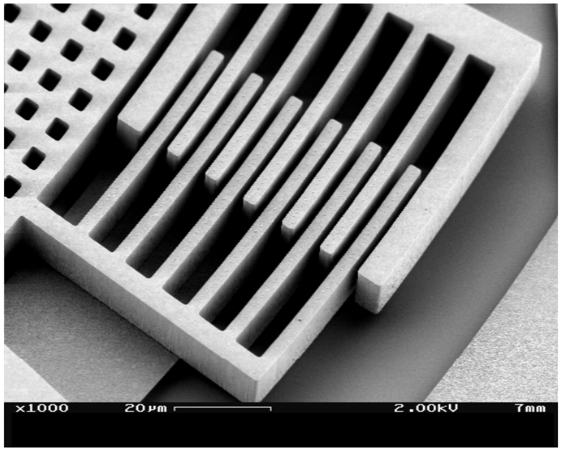
Examples of MEMS fabrication using CMP

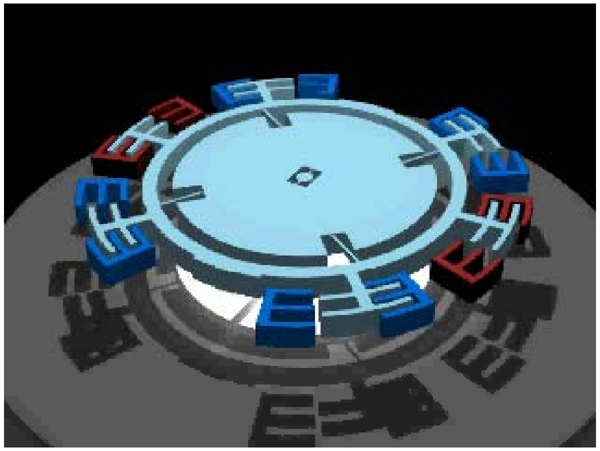
poly-Si angular rate sensor

Goal

Moving poly-Si comb (capacitor) structures for acceleration and angular rate sensors (gyros), height >10 µm, space 1 µm.

Coriolis-force angular rate sensor



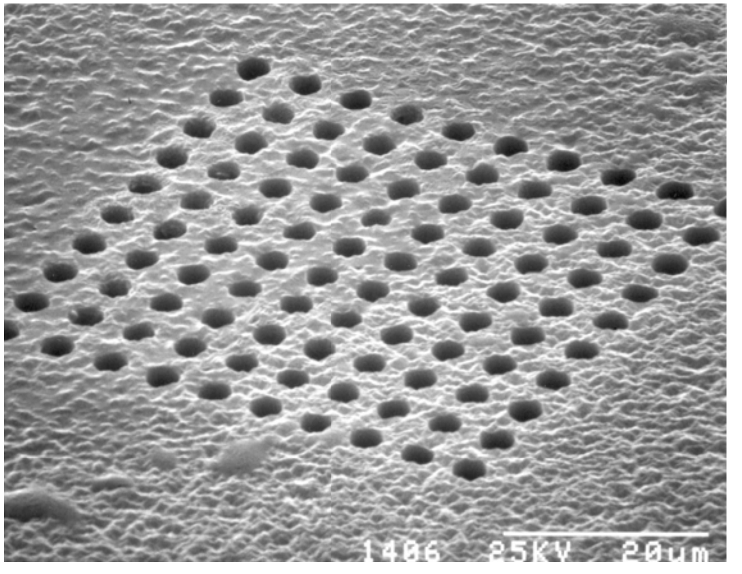


Examples of MEMS fabrication using CMP

poly-Si angular rate sensor

Problem

Thick poly-Si (> 10 µm) layers show a rough surface after deposition ($R_a \approx 1$ µm) $\rightarrow$ CMP



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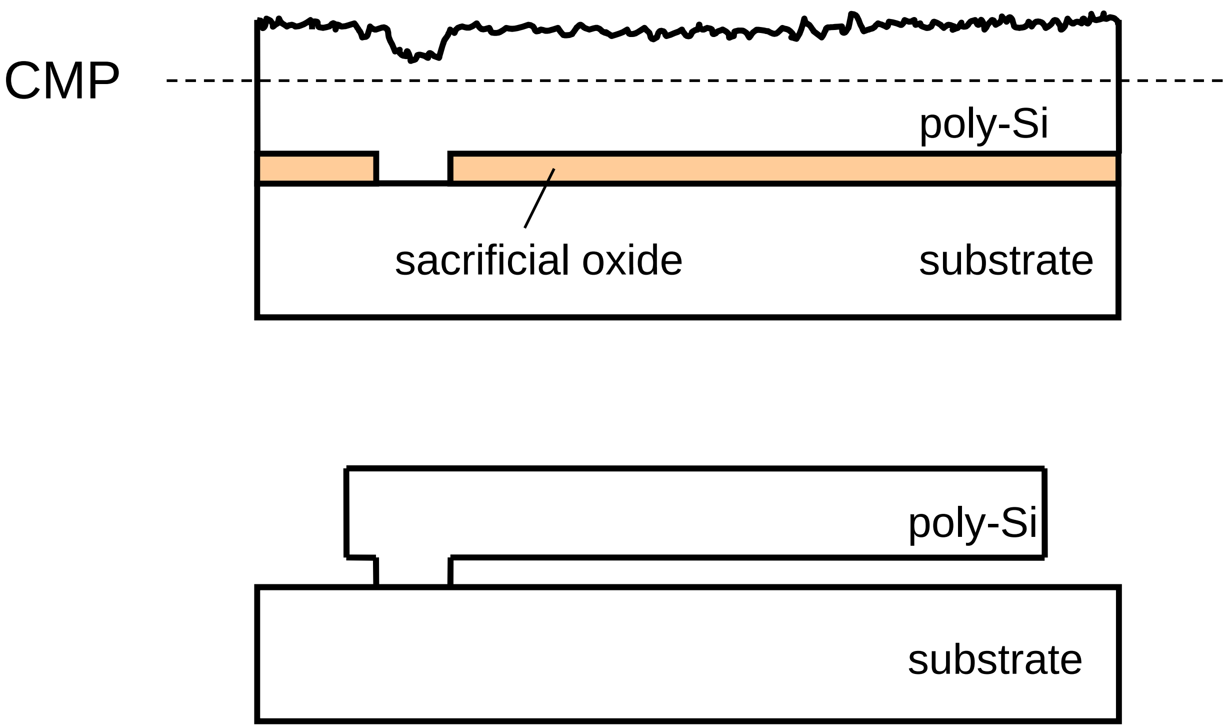
Examples of MEMS fabrication using CMP

poly-Si angular rate sensor



Sensor fabrication sequence:

- Deposition of sacrificial oxide
- Etching of anchor openings
- Deposition of thick poly-Si (>10 µm)
- CMP of poly-Si
- Etching of comb structures by DRIE
- Etching of sacrificial oxide by vapour phase HF etch

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Examples of MEMS fabrication using CMP

poly-Si angular rate sensor

CMP results

Poly-Si CMP

Starting poly-Si thickness ≈ 14 µm

Final poly-Si thickness = 11,35 µm

Final poly-Si layer non-uniformity < ± 200 nm (range)

CMP Process

Cabot SS25 fumed silica based SiO_2 slurry

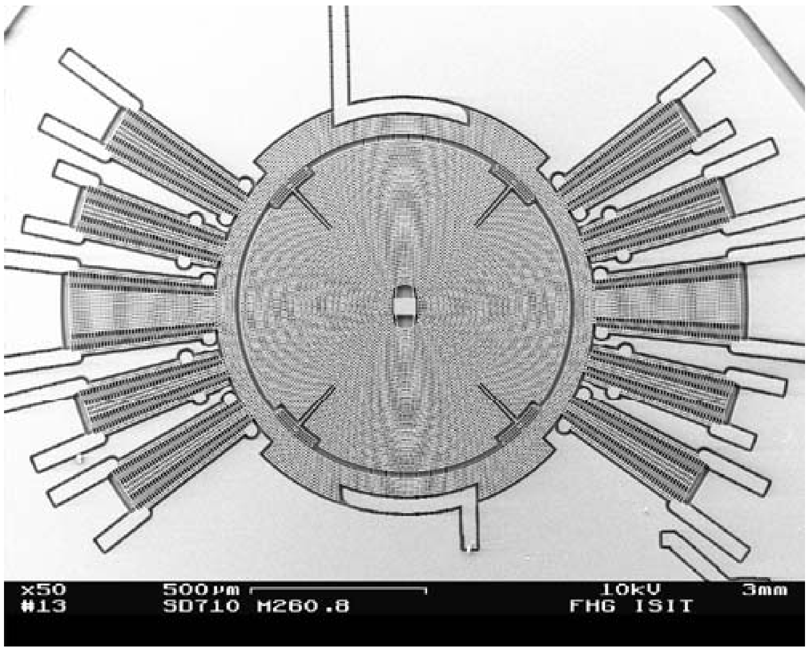
Removal Rate ≈ 0.5 µm/min

WIWNU < 2% (~55 nm (1 σ)) on 150 mm wafers

$R_a \approx$ 0.3 - 0.5 nm after Fujimi Glanzox buff

Examples of MEMS fabrication using CMP

poly-Si angular rate sensor



Sensor + ASIC in MCM:

Signal range ± 300°/s

Signal bandwidth 12 – 200 Hz

Applications:

Vehicle dynamic control

Car navigation

Virtual reality

Development Partner:

SensorDynamics AG

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sensordynamics

Examples of MEMS fabrication using CMP

case studies

- poly-Si angular rate sensor
- infrared digital micro mirror array
- capacitive RF-MEMS switch

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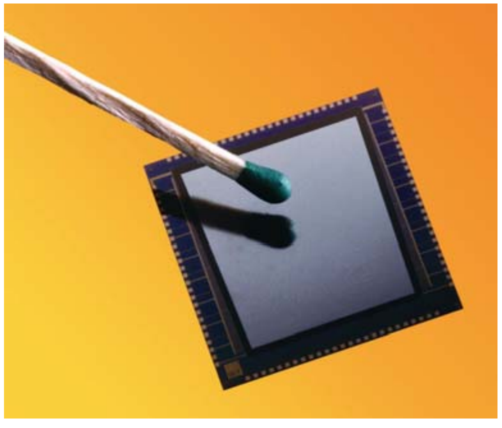
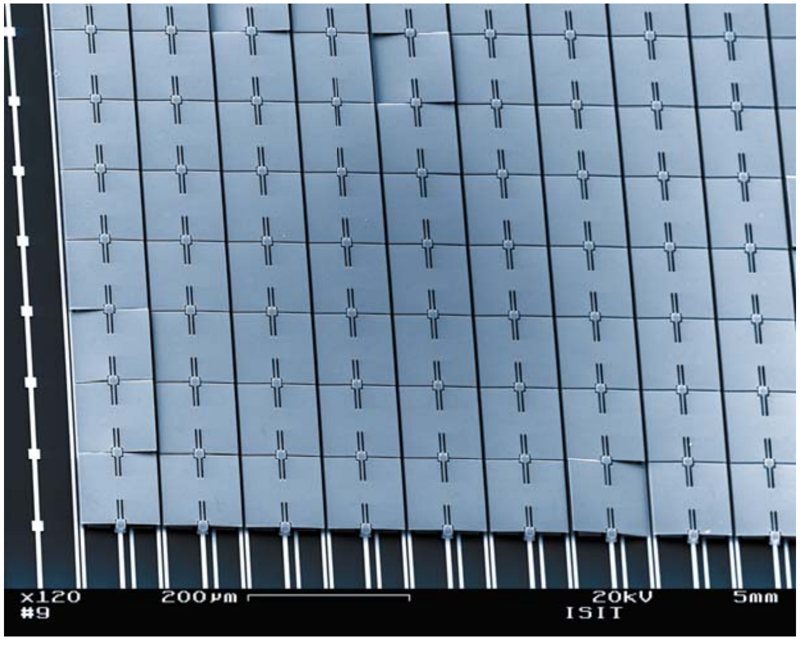
Examples of MEMS fabrication using CMP

infrared digital micromirror array





256 x 256 pixel micro-mirror array for infrared imaging system

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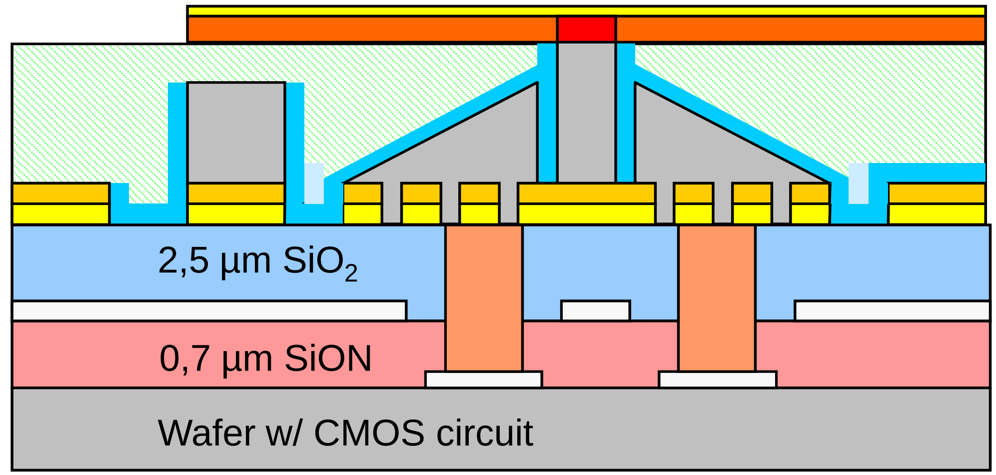
Examples of MEMS fabrication using CMP

infrared digital micromirror array

CMP 3: Cu sacrificial layer
~ 10 µm thickness
stop on Ni posts

CMP 2: Cu damascene incl.
TaN barrier

CMP 1: Oxide planarization
of CMOS passivation



3 CMP steps needed in the fabrication process

Examples of MEMS fabrication using CMP

infrared digital micromirror array

Results of thick Cu CMP 3

Cu-CMP slurry: Commercial product with inherently high selectivity to Nickel (Cabot iCue®5003) on IC1000 k-grv.

Removal rate > 0.5 µm/min

Polishing time > 5 min, in-situ conditioning

Roughness R_a < 3 nm

High selectivity to Nickel posts achieved

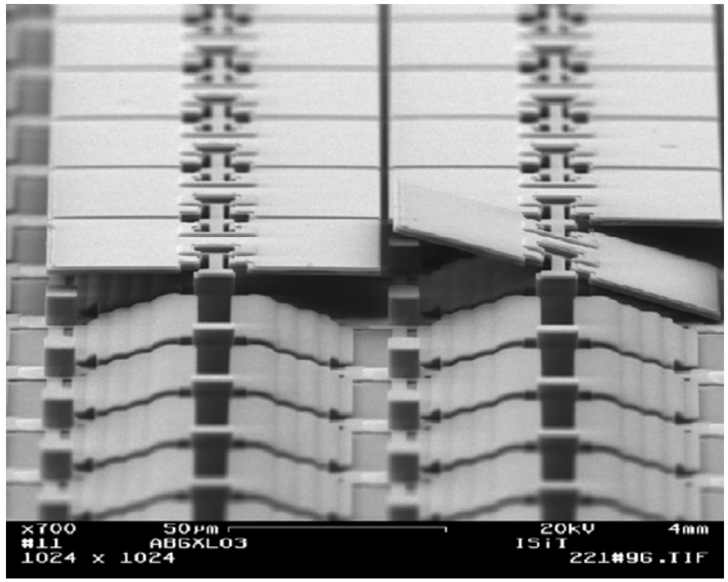
Dishing between Nickel posts < 100 nm
for mirrors 80 x 80 µm size

→ sufficiently flat for IR applications

Examples of MEMS fabrication using CMP

infrared digital micromirror array

Final device



Mirror array with tilted mirror after CMP 3
and copper sacrificial layer etch

Examples of MEMS fabrication using CMP

case studies

- poly-Si angular rate sensor
- infrared digital micro mirror array
- capacitive RF-MEMS switch

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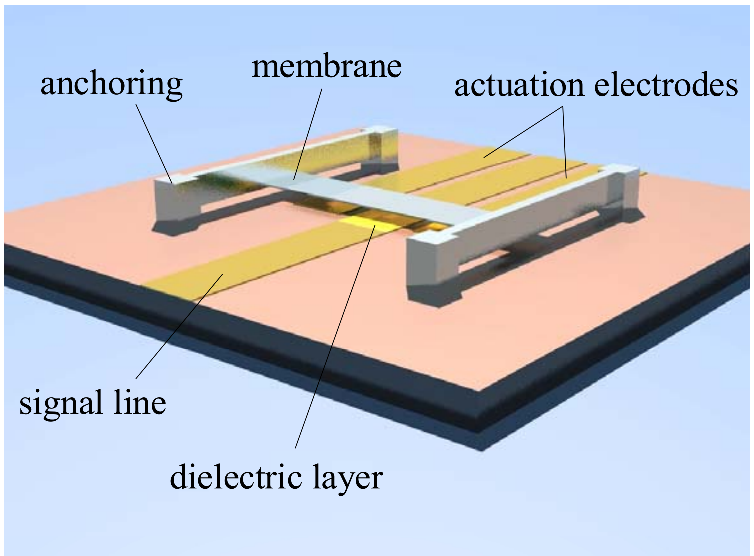
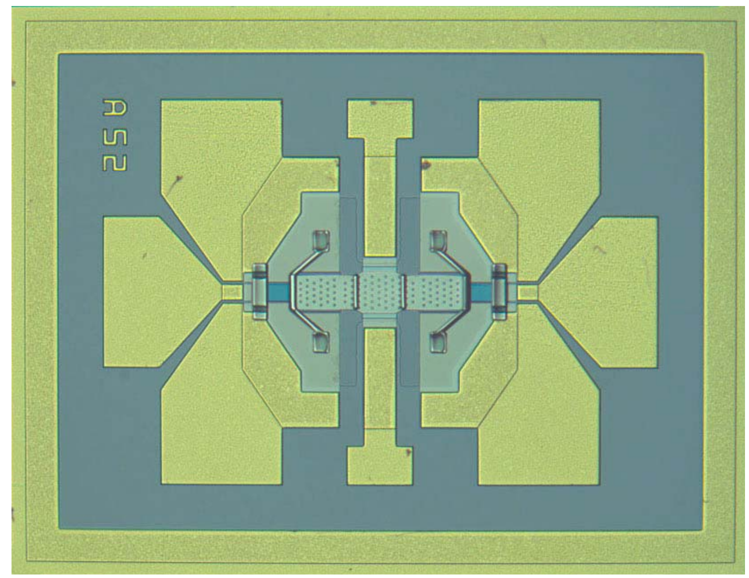
Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch
manufactured with Cu sacrificial layer



schematic 3D-view of capacitive switch

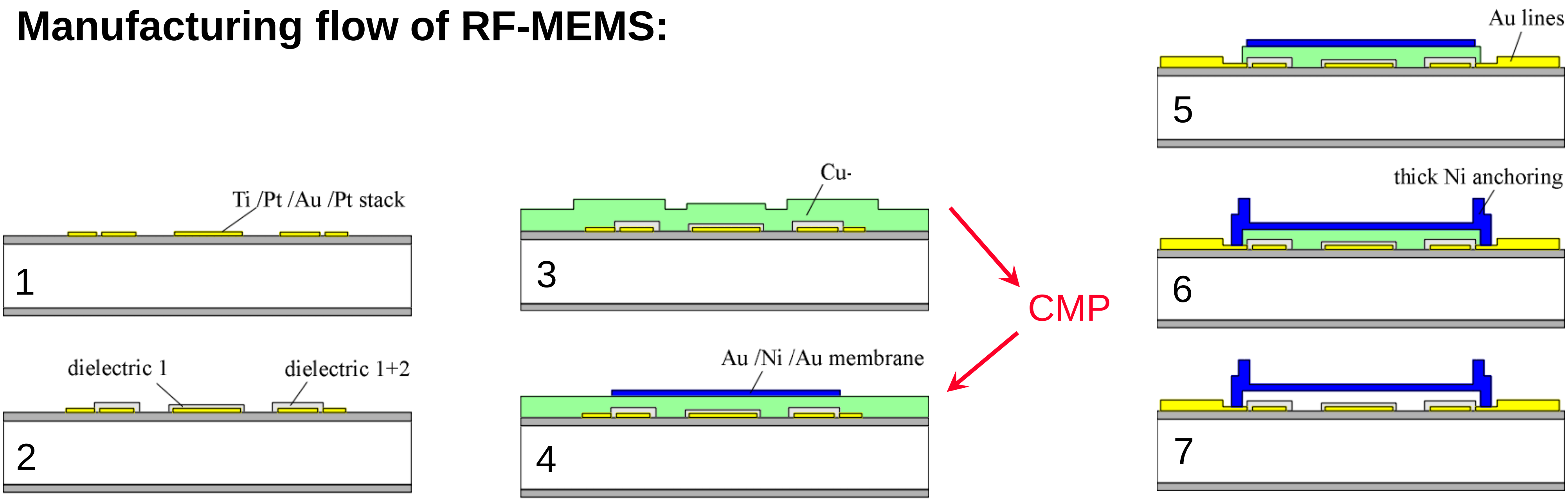


20 GHz capacitive RF-MEMS switch

Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch

Manufacturing flow of RF-MEMS:



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Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch

Final Cu sacrif.-layer thickness: 2.85 µm

Which Cu starting thickness is required for a planarity < 50 nm ?

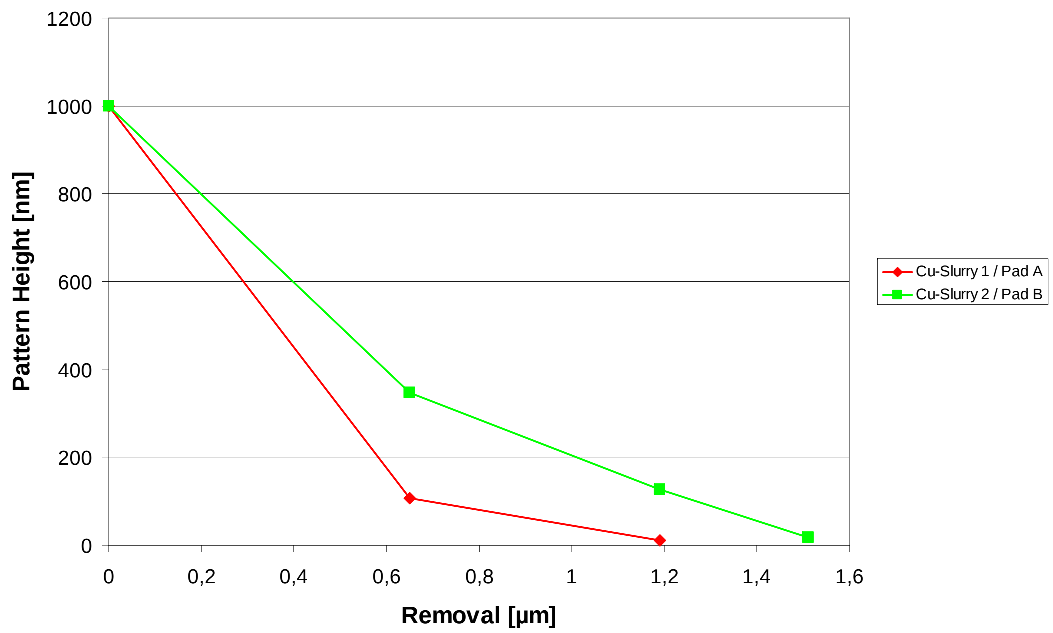
1 µm pattern height

reduction depending on

- polishing time (removal)
- consumables set (pad, slurry)

→ Cu start thickness: 4.5 µm

1.65 µm Cu to be removed by CMP



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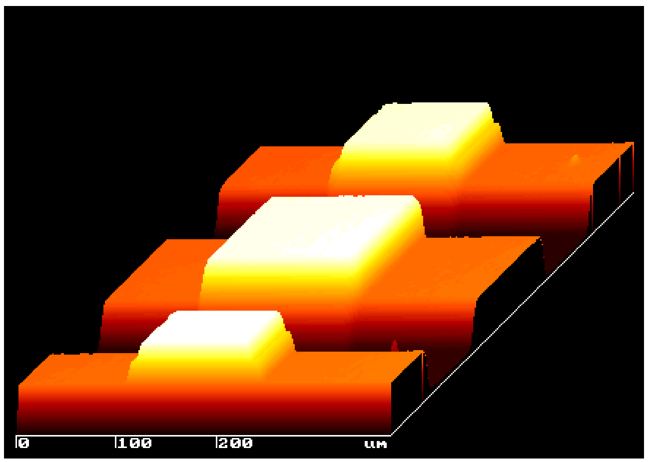
Examples of MEMS fabrication using CMP

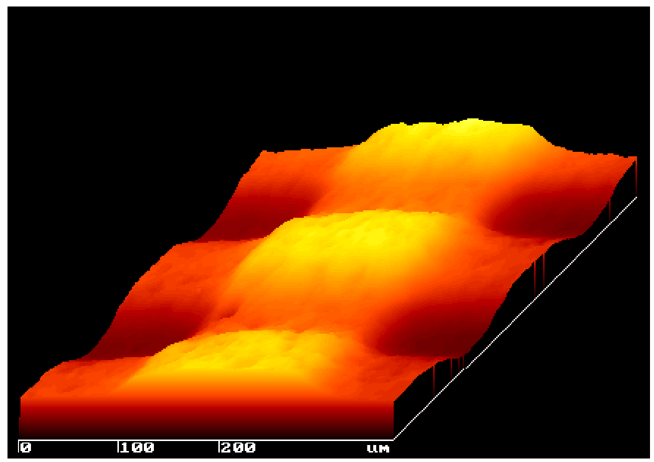
capacitive RF-MEMS switch

Evolution of planarity (Cu-Slurry 2 / Pad B)



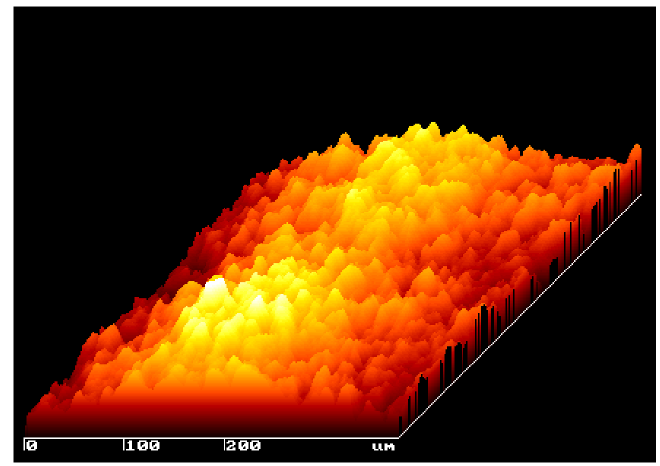
unpolished

pattern height 1000 nm



0.64 µm mean removal

pattern height 346 nm



1.51 µm mean removal

pattern height 17 nm

R_a (plane) = 2.0 nm

micromap 512 white-light interferometer

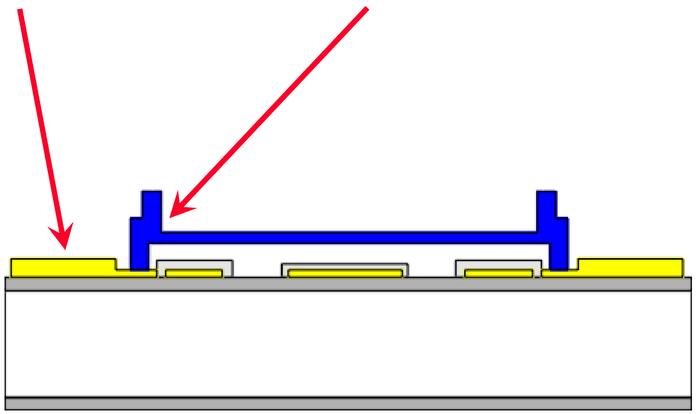
Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch v 2.0

Simultaneous formation of Cu sacrificial layer and membrane contacts

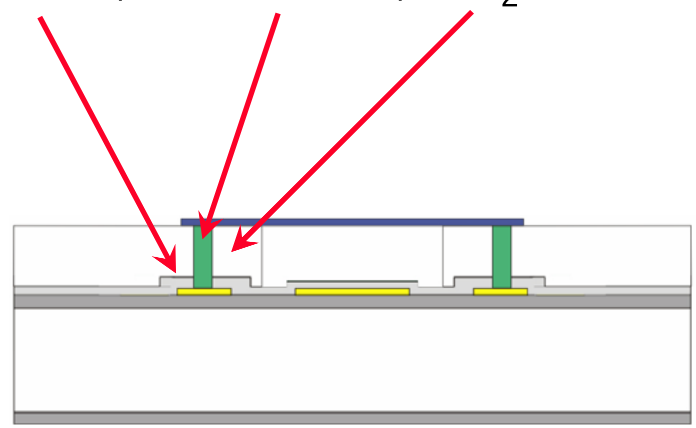
Conventional RF-switch:

Au lines, Ni anchoring & contact



RF-switch with damascene contacts:

Au lines, Cu contacts, SiO_2 anchoring



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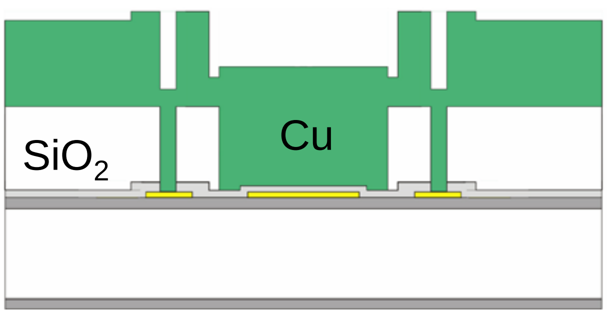
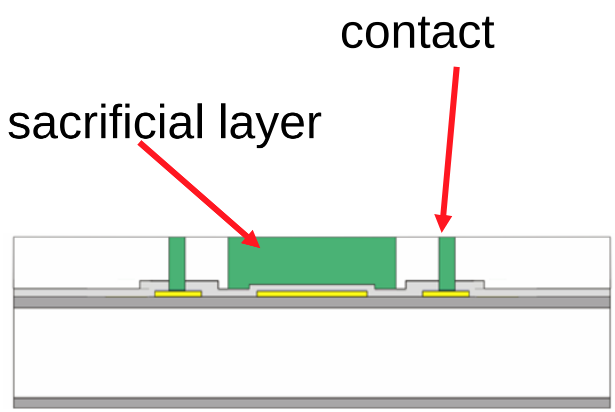
Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch v 2.0

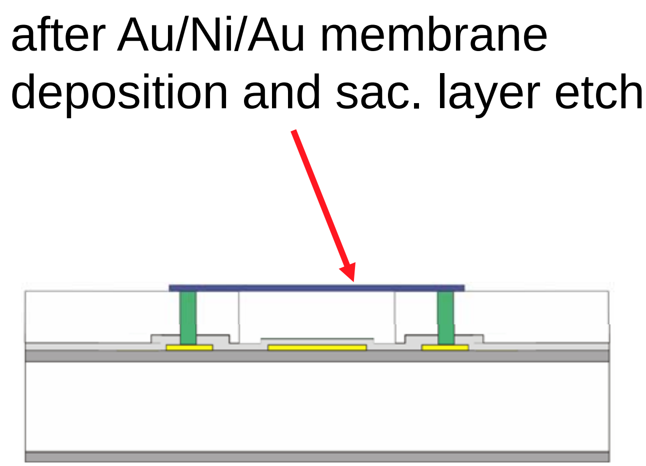
Cu damascene contacts:



before CMP
- 3.6 µm oxide
- 5 µm copper



after Cu/oxide CMP
- 3.2 µm oxide
- copper contacts and sac. layer



Cu contacts
SiO$_2$ anchoring

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Examples of MEMS fabrication using CMP

capacitive RF-MEMS switch

Encountered Problems:

- Layer stress: 5 µm Cu leads to a wafer deformation of 150 µm
- Planarization of 3.6 µm high steps → slurry with high Cu RR of > 500 nm required
- Overpolish into SiO_2 to achieve oxide planarity → slurry with 1 : 1 selectivity required
- Low dishing for flat membrane to avoid buckling

→ Various pad/slurry combinations and/or process schemes under evaluation

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Further Examples

applications of CMP for MEMS-related fabrication

Wafer bonding	• Si-CMP for direct wafer bonding • oxide CMP for anodic bonding • grinding/polishing of glass frit for „laser soldering“ (encapsulation of micro sensors)
Backside CMP	• grinding/polishing of Si - replacement of double-side polished wafers - ultra-thin silicon: stress relief after grinding
3D integration (TSVs)	• metal CMP for removal of material overburden

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Opportunities for the CMP Consumables Manufacturers

Polishing pads	• larger structures require stiffer pads w/ low defectivity • other pad/sub-pad combinations to be tested
Polishing slurries	• thicker layers need higher RRs: customized solutions • new/other materials to be CMPed
Conditioners	• adapted conditioners for more aggessive polishing
Brush rollers	• 3D structures: danger of brush tear out
Cleaning chemicals	• layer-specific solutions needed

Outlook

MEMS market volume nearly doubles from 2007 – 2012, number of units triples

Expansion on new applications and additional layer materials:

CMP ?

- SiC, Si_3N_4, SiGe, Ge (sac. layer, H_2O_2 etch), Ni, Au
- amorphous/polycrystalline CVD diamond
  (high wear resistance, hydrophobic, chemically innert)
- low-cost substrates: glass, polymers, metals, ceramic
- piezo materials (PZT) for actuators
- ...

Summary

- CMP is an “enabling technology” for the manufacturing of advanced integrated circuits
- CMP is deployed increasingly for the fabrication of modern MEMS devices
- CMP technology requirements:
  - ever decreasing device structure dimensions in microelectronic manufacturing
  - large structure dimensions in MEMS fabrication
- Future trends: 3D integration, packaging, new materials, new applications

Thank You