MEMS Inteligentné senzory a aktuátory

Ing. Richard Balogh

Technológia MEMS

14. 4. 2020

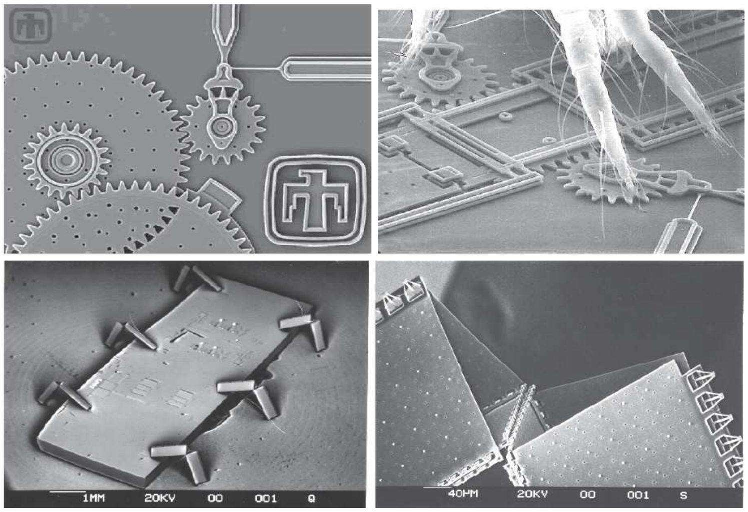
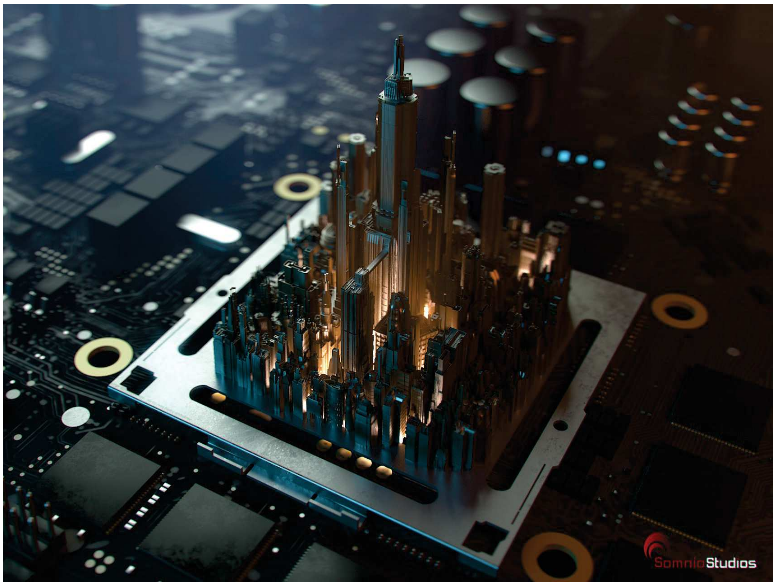
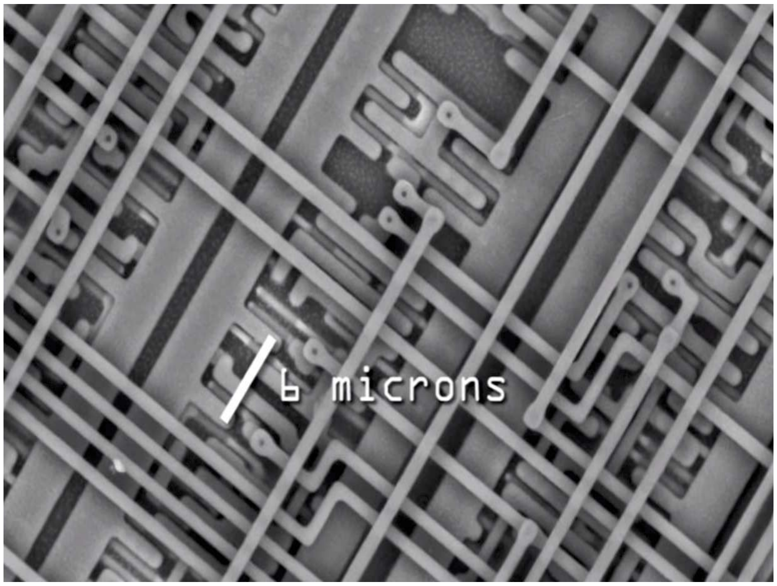


Figure 3: (top left) Sandia gear train, typical of MEMS micromotor parts.[14] (top right) Sandia gear train, with spider mite leg for size comparison.[15] (bottom left) Berkeley silicon bug prototype walking robot.[16] (bottom right) Detail of elbow joint hinge on previous silicon bug.[16]





2. Technológie

1796 – Litografia

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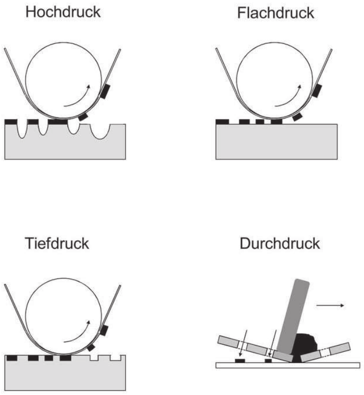
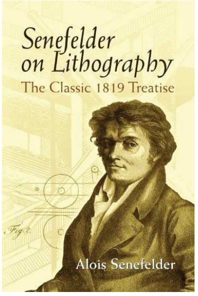
1796 – Litografia




Senefelder on Lithography
The Classic 1819 Treatise
Alois Senefelder

Alois Johann Nepomuk Franz Senefelder bol rakúsky herec, vynálezca a dramatik. Roku 1796 vynašiel litografiu. Ako herec mal problémy s včasným a lacným vytlačením divadelných hier, tak sa preto pokúšal o rôzne spôsoby, ktoré by mu to umožňovali.

* 6. novembra 1771, Praha, Česko
\+ 26. februára 1834, Mníchov, Nemecko

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2. Technológie

1820 – Fotografia

Joseph Nicéphore Niépce

Sýrsky asfalt

Pohľad z okna v Le Gras, cca 1826 – jedna z prvých Niépceho fotografií.

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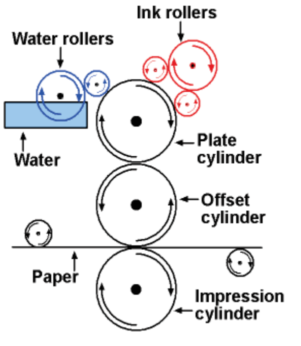
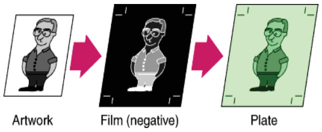
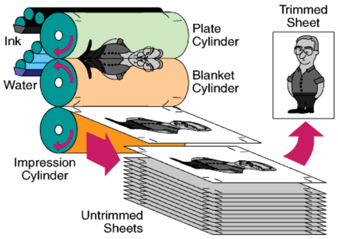
2. Technológie

1875 – Fotolitografia (ofset)







1875 patent by Robert Barclay
1901 by Ira Washington Rubel (+foto)

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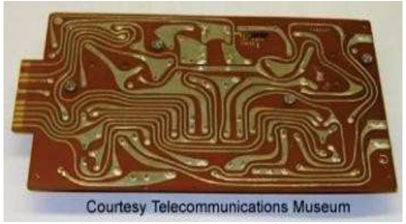
2. Technológie

1936 – Plošné spoje

https://www.autodesk.com/products/eagle/blog/history-of-pcbs/

Paul Eisler
(1907 – 26 October 1992, London)
Austrian inventor born in Vienna.


Courtesy Telecommunications Museum

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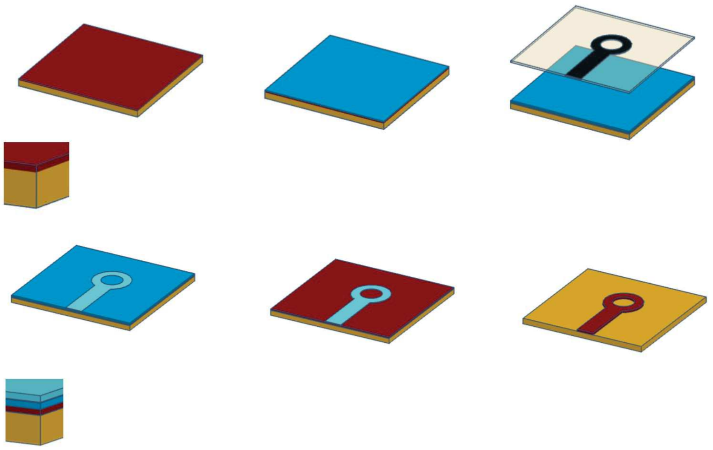
2. Technológie

Plošné spoje



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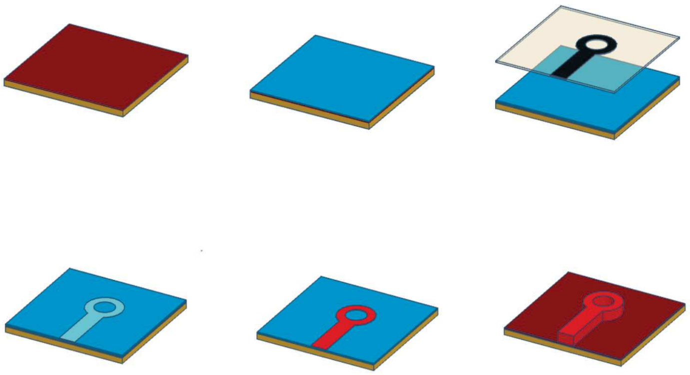
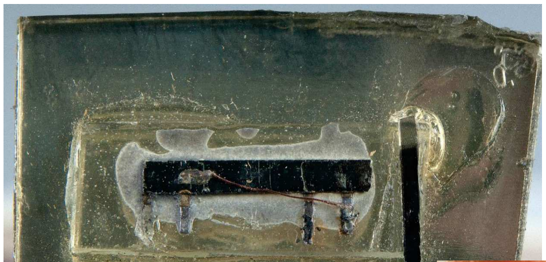
2. Technológie

Plošné spoje

λ – vlnová dĺžka!



2. Technológie 1936 – Integrovaný obvod



Jack Kilby's original hybrid integrated circuit from 1958 made in Texas Instruments.

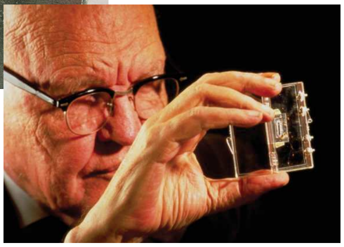
This was the first integrated circuit, and was made from germanium.

Image: Smithsonian, USA

Jack Kilby
(8. 11. 1923 – 20. 6. 2005)

Americký inžinier a vynálezca (integrovaný obvod, kalkulačka, termotlačiareň),

Nobelova cena 2000



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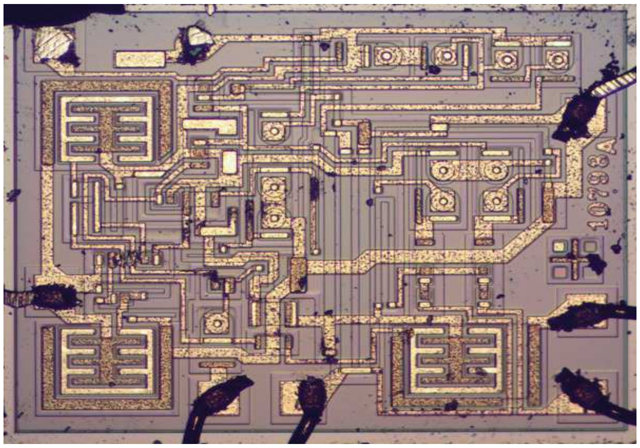
2. Technológie
CMOS

Die photo of the 555 timer.

Source: http://www.righto.com/2016/02/555-timer-teardown-inside-worlds-most.html



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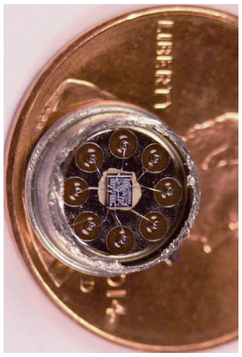
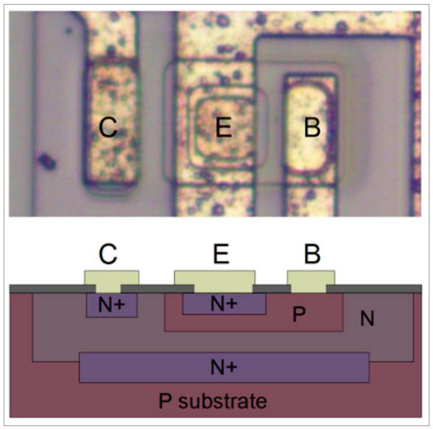
2. Technológie
CMOS





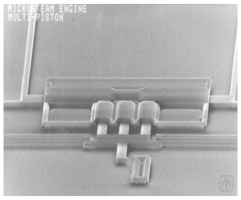
An NPN transistor in the 555 timer chip.

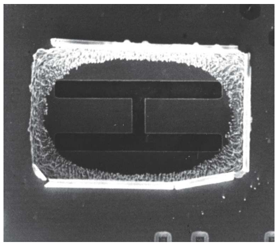
Využitie mikrosystémovej techniky pri výrobe MEMS a mikrosenzorov

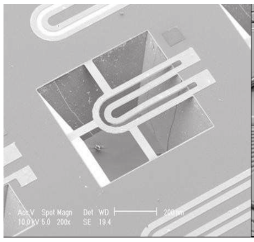
Ing. Gabriel VANKO, PhD.
Elektrotechnický ústav SAV Bratislava

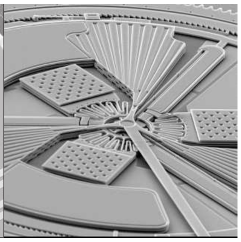
MEMS – Mikro-Elektro-Mechanické-Systémy

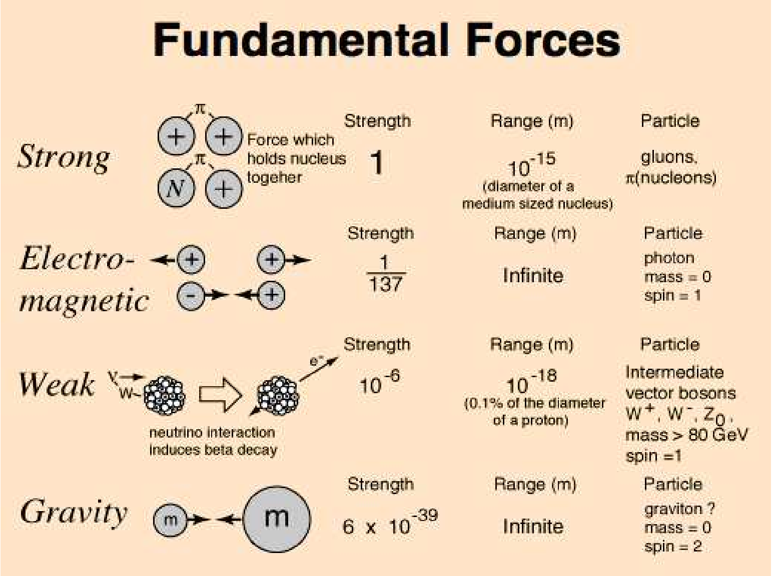
Rozmery 1μm - 1mm











Fundamental Forces

	Strength	Range (m)	Particle
Strong	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic	$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity	6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

Force which holds nucleus togeher

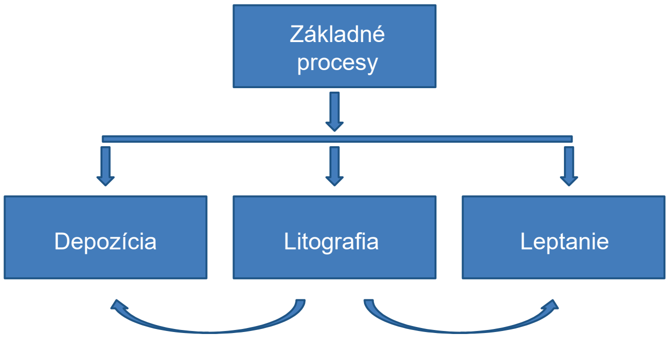
neutrino interaction induces beta decay

Využitie

- “normálne” podmienky
- **atramentové tlačiarne** – nanášanie atramentu
- **akcelerometre** – moderné autá (airbag), hracie zariadenia (ovládače), digitálne kamery, mobily, zobrazovače
- **gyroskopy**
- **tlakové senzory** – nosníky, mostíky, mikrofóny v mobiloch
- optické spínače
- medicína – biosenzory, chemosenzory (Lab-On-Chip)

- “extrémne” podmienky
- letectvo
- námorníctvo
- kozmonautika
- energetika

Technológia



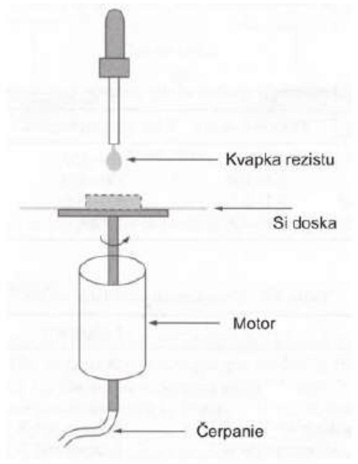
Základné procesy

Depozícia

Litografia

Leptanie

Nanášanie rezistu



A – odmastenie vzorky

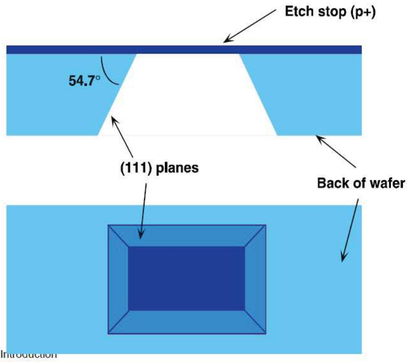
B – nanesenie rezistu

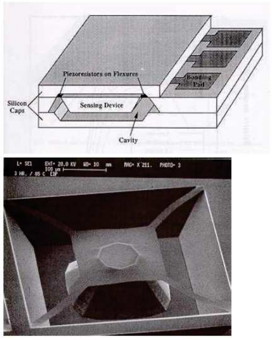
s presnou hrúbkou

C – vypekanie

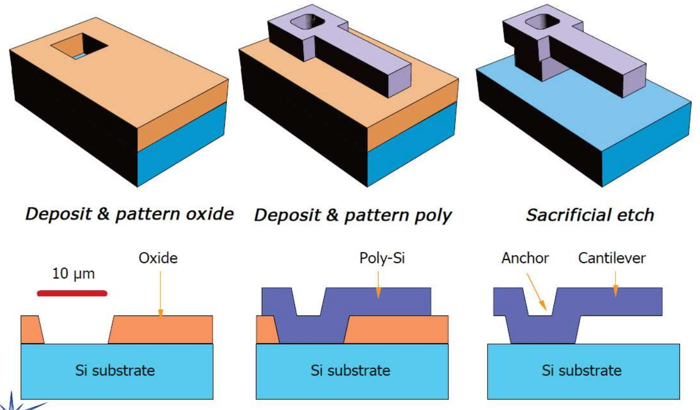
Bulk Micromachining

- Key concept: Mechanical part is formed out of the substrate material
- Example: Bulk-micromachined pressure sensor etched w/KOH or EDP



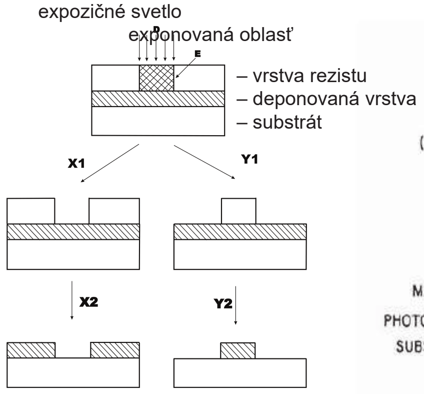


Surface Micromachining



Deposit & pattern oxide *Deposit & pattern poly* *Sacrificial etch*

Fotolitografia



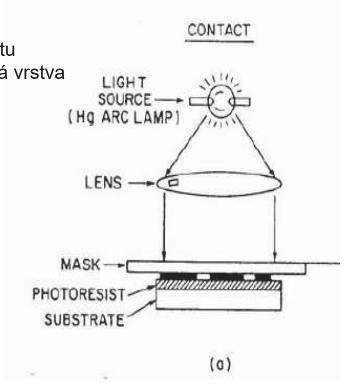
expozičné svetlo

exponovaná oblasť

– vrstva rezistu

– deponovaná vrstva

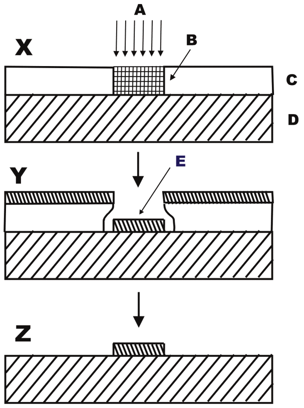
– substrát



X1,X2 – pozitívny proces

Y1,Y2 – negatívny proces

Technika „lift-off“



A - expozičné svetlo

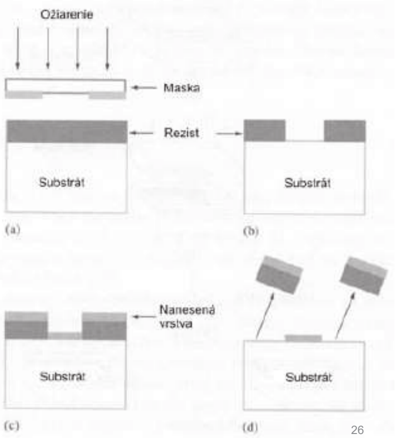
B - exponovaná oblasť

C - fotorezist

D - substrát

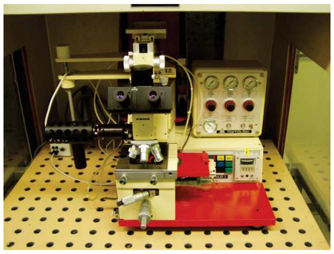
E - deponovaná vrstva

Technika „lift-off“



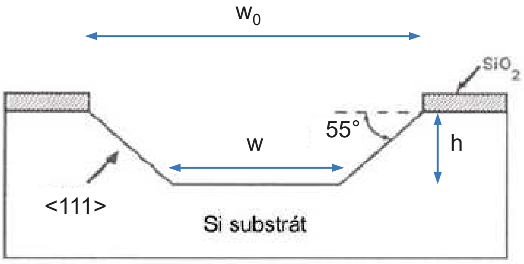
1000 (US norma), 1000 častíc (< 0.5 μm) /stopa^3 (ISO 5), vlhkosť: 40 % ± 1 %, teplota: 22 °C ± 1 °C

SÜSS MJB 21 Mask Aligner



SÜSS MJB 3 Mask Aligner

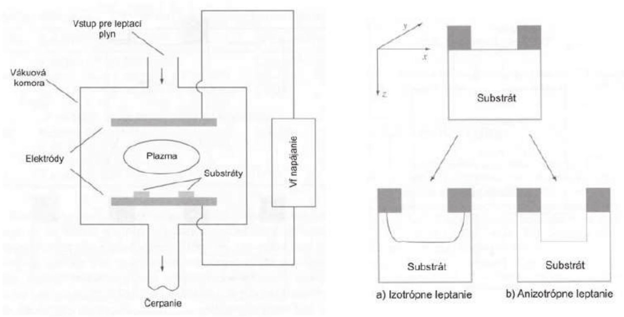
Mokré leptanie



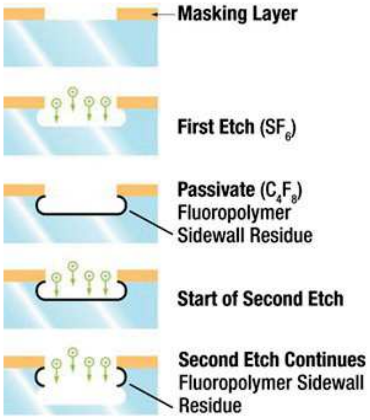
$w = w_0 - 2h \coth(55°)$ alebo $w = w_0 – 1{,}4h$

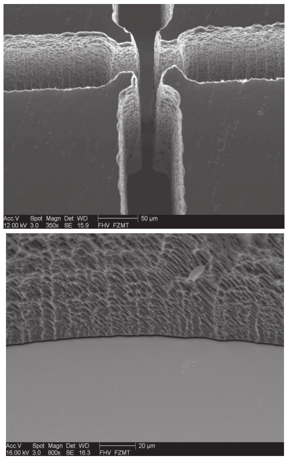
$100 + 1{,}4 \cdot 300 = 520$

Suché leptanie

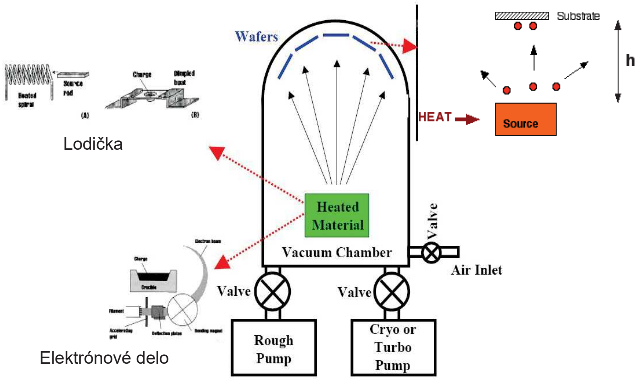


Bosch process





Naparovanie



Lodička

Elektrónové delo

Naparovanie

The step coverage of evaporated films is poor due to the directional nature of the evaporated material (shadowing) (see figure 12-5). Heating (resulting in surface diffusion) and rotating the substrates (minimizing the shadowing) help with the step coverage problem, but evaporation can not form continuous films for aspect ratios (AR=step height/step width or diameter) greater than 1.

We need a less directional metalization scheme====> Higher pressures!

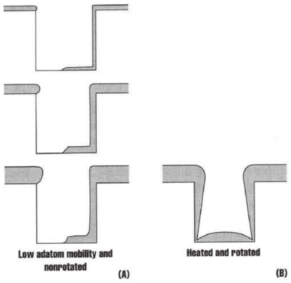
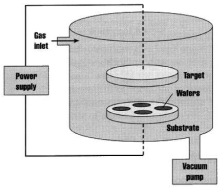


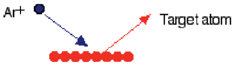
Figure 12-5 (a) Time evolution of the evaporative coating of a feature with aspect ratio of 1.0, with little surface atom mobility (i.e., low substrate temperature) and no rotation. (b) Final profile of deposition on rotated and heated substrates.

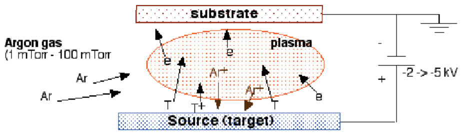
Naprašovanie

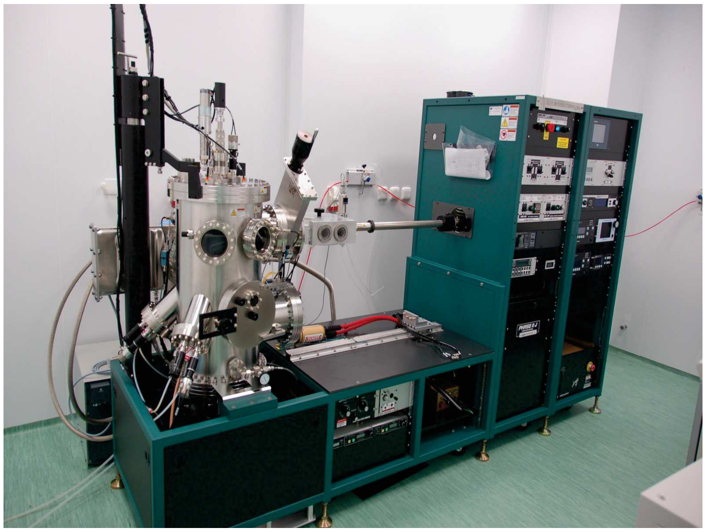
Výhody: lepšie pokrytie, menšie radiačné poškodenie, nanášanie zliatin

Nevýhody: poškodenie spôsobené plazmou







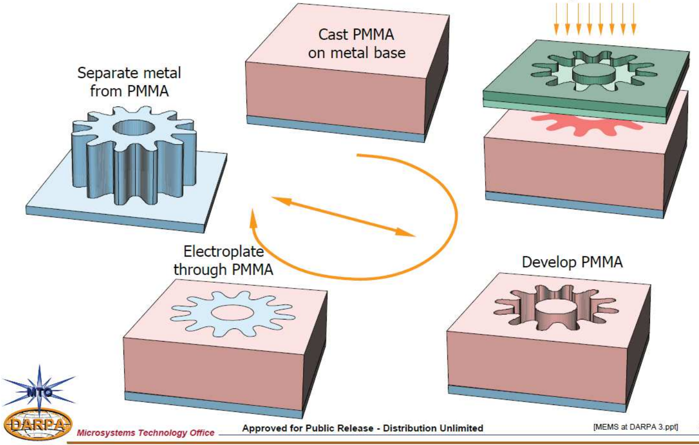


Naparovanie elektrónovým zväzkom

Naprašovanie

LIGA Process

LIthographie Galvanoformung Adformung



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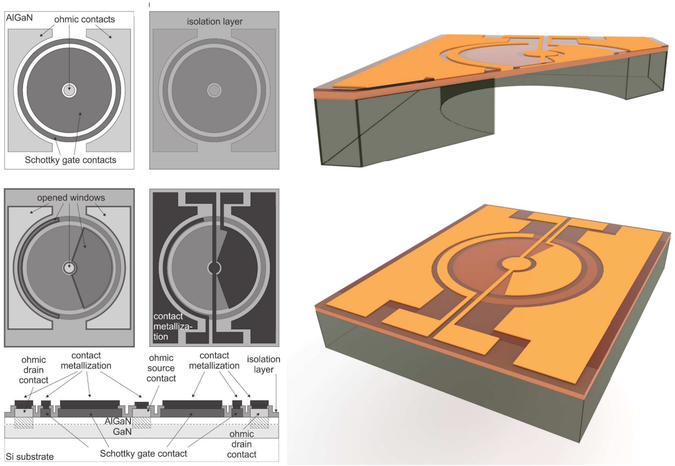
<BACK

Layout



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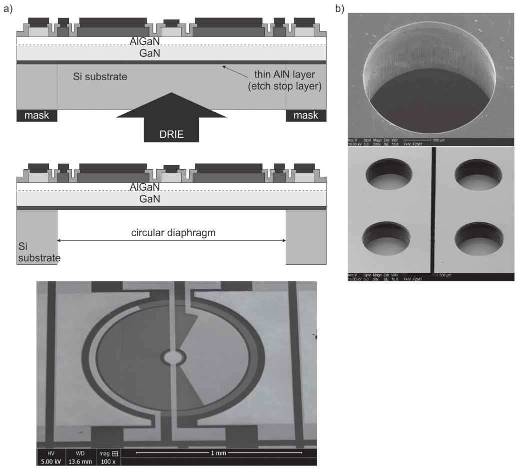
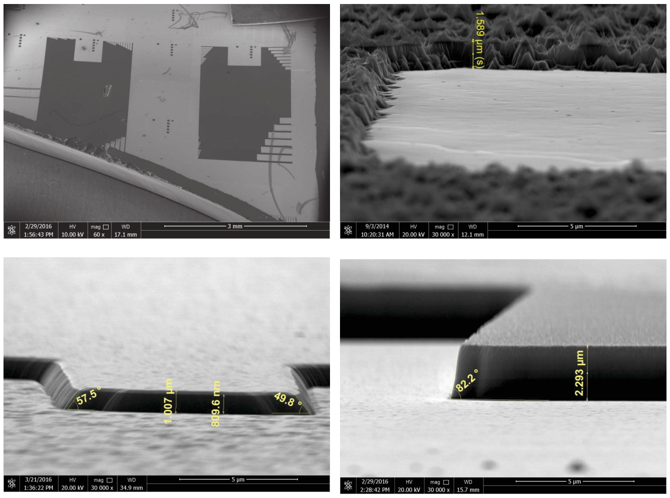
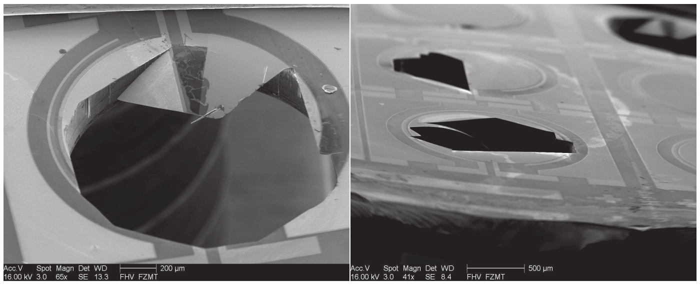
Súčiastka

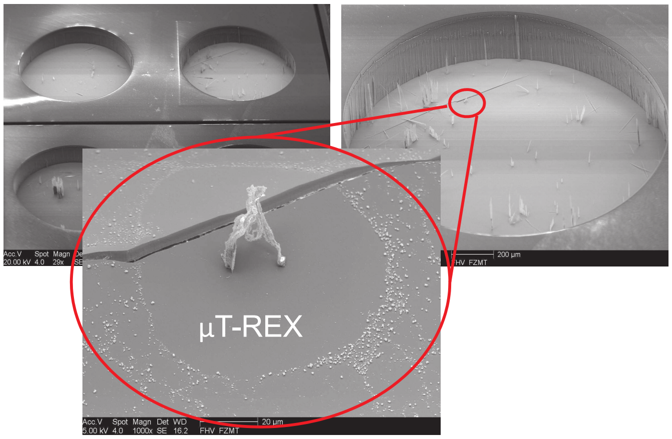


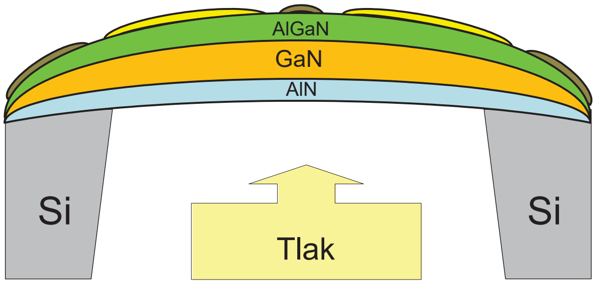


Praskanie membrán



Praskanie membrán





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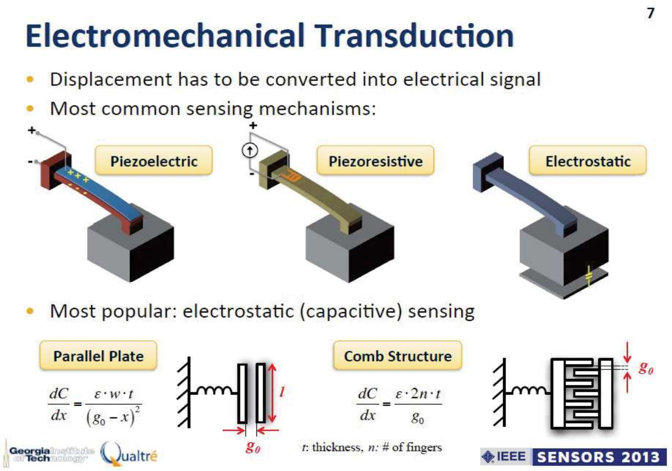
9. 4. Meranie zrýchlenia



Electromechanical Transduction

- Displacement has to be converted into electrical signal
- Most common sensing mechanisms:

- Most popular: electrostatic (capacitive) sensing

Parallel Plate

$$\frac{dC}{dx} = \frac{\varepsilon \cdot w \cdot t}{(g_0 - x)^2}$$

Comb Structure

$$\frac{dC}{dx} = \frac{\varepsilon \cdot 2n \cdot t}{g_0}$$

t: thickness, n: # of fingers

Georgia Institute of Technology Qualtré IEEE SENSORS 2013

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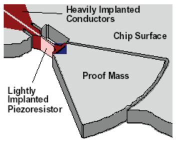
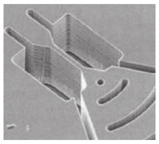
9. 4. Meranie zrýchlenia

MEMS akcelerometer

- Piezoresistive MEMS accelerometer
  - Operating Principle: a proof mass attached to a silicon housing through a short flexural element. The implantation of a piezoresistive material on the upper surface of the flexural element. The strain experienced by a piezoresistive material causes a position change of its internal atoms, resulting in the change of its electrical resistance
  - low-noise property at high frequencies





Courtesy of JP Lynch, U Mich.

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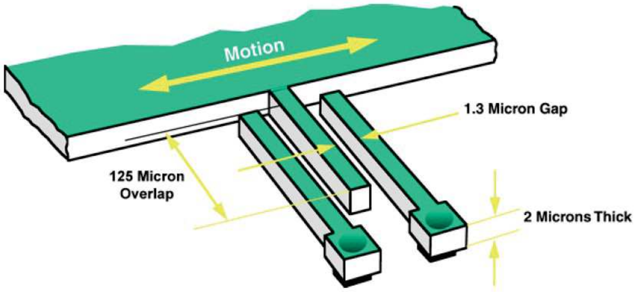
9. 4. Meranie zrýchlenia

MEMS akcelerometer



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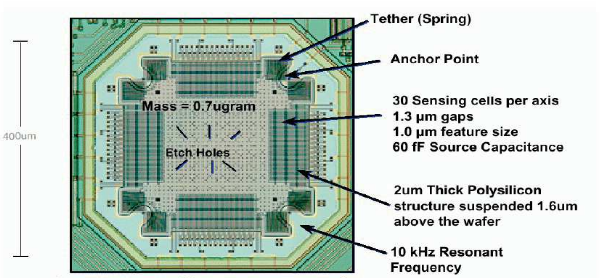
9. 4. Meranie zrýchlenia

MEMS akcelerometer

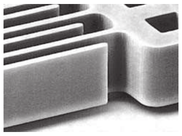
ADXL 202: Micromachined Beam

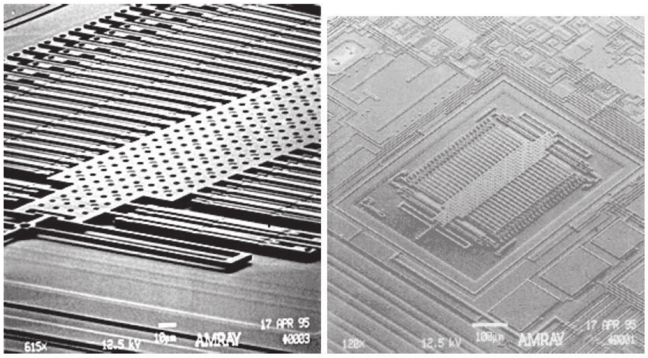


Deflection due to 2 *g* Acceleration = 5 nm = 250aF (250×10^{-18} F)
Minimum Resolvable Deflection = 0.04Angstroms = 90zF (90×10^{-21} F)
Beam Deflects 0.4% of gap under a 2 *g* Force

9. 4. Meranie zrýchlenia

MEMS akcelerometer





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9. 4. Meranie zrýchlenia

MEMS akcelerometer