

Obsah

Využitie mikrosystémovej techniky pri výrobe MEMS a mikrosenzorov

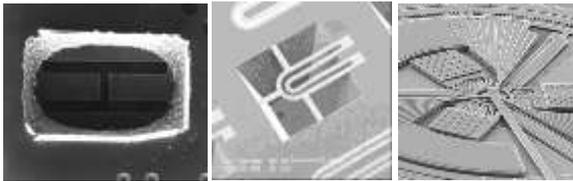
- Čo sú to MEMS?
- Ako ich vyrobiť?
- Ako ich merať?
- MEMS tlakový senzor

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MEMS

- Mikro-Elektro-Mechanické-Systémy

Rozmery 1 μ m - 1mm

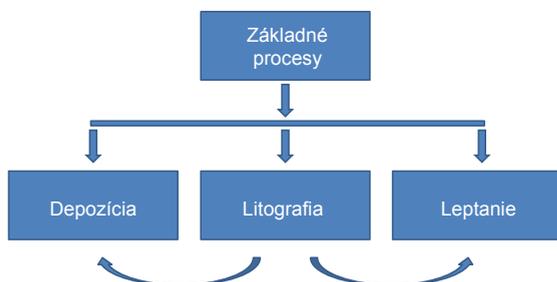


Využitie

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

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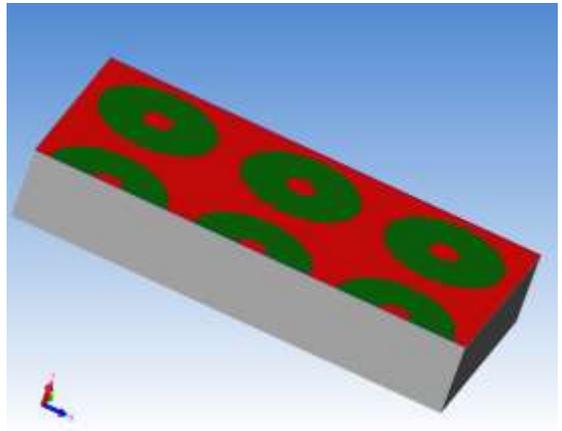
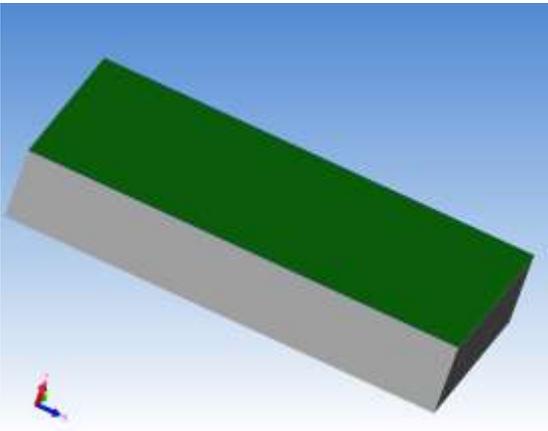
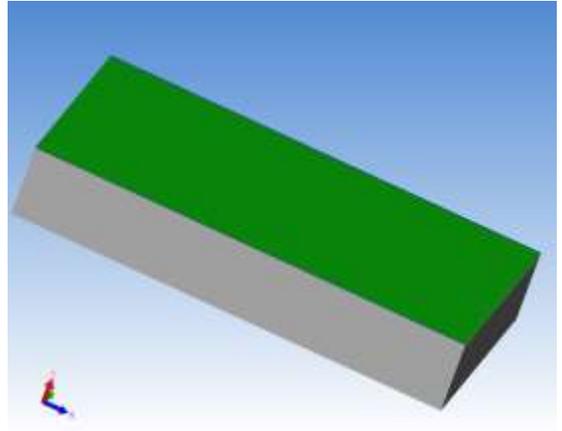
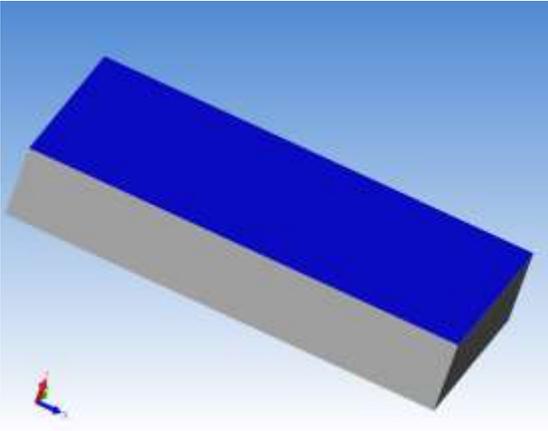
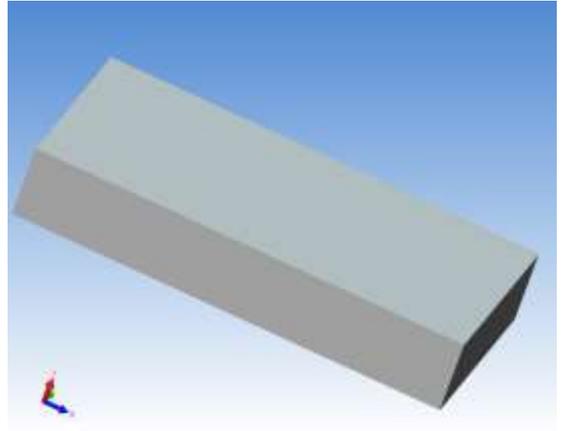
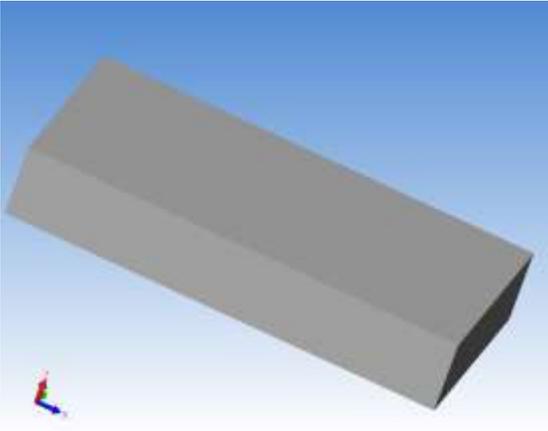
Technológia

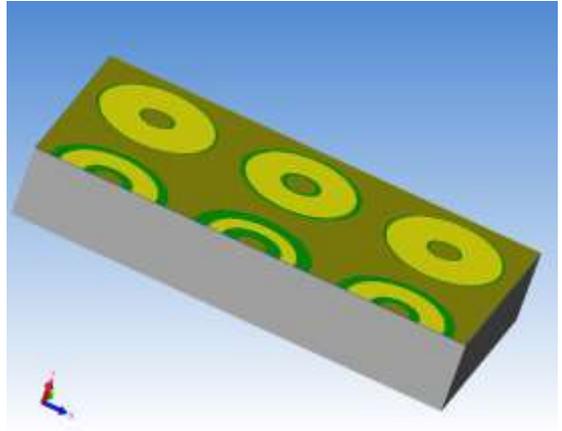
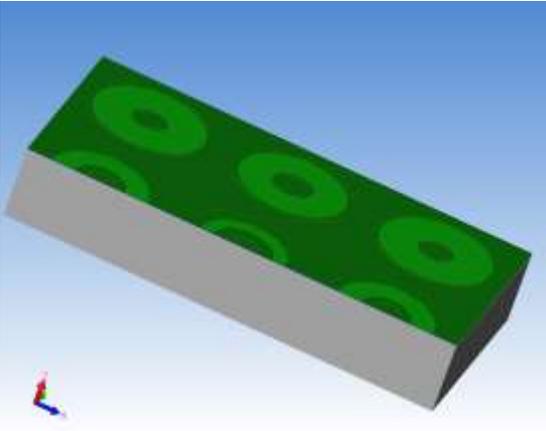
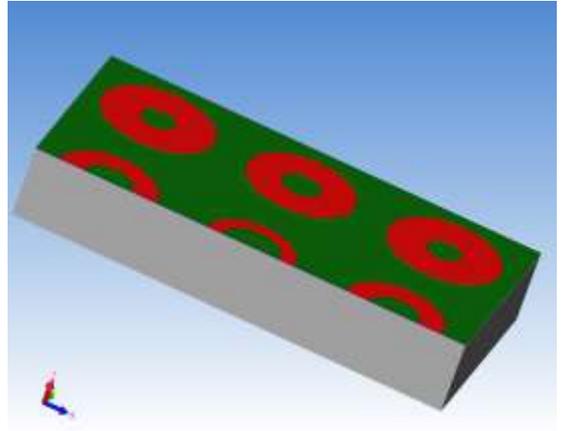
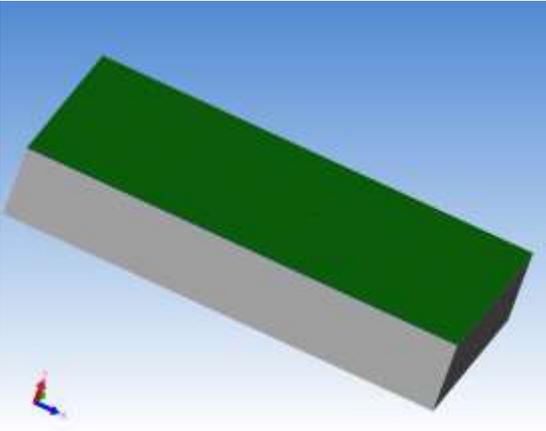
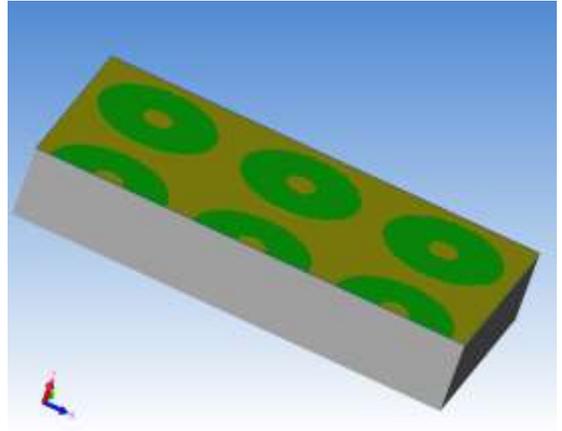
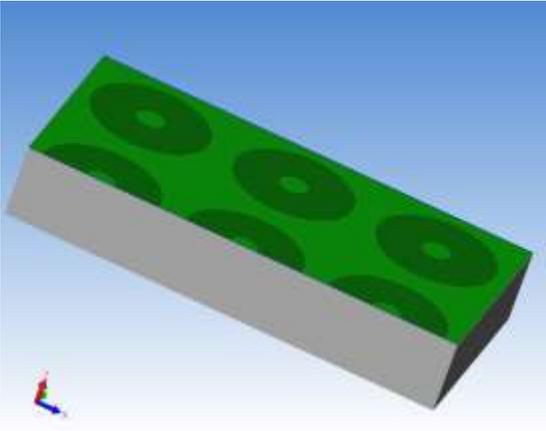


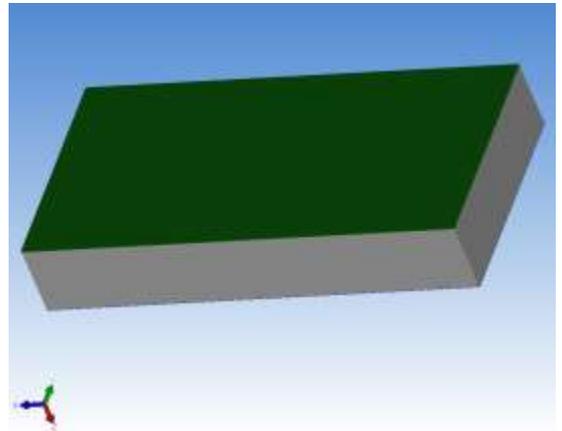
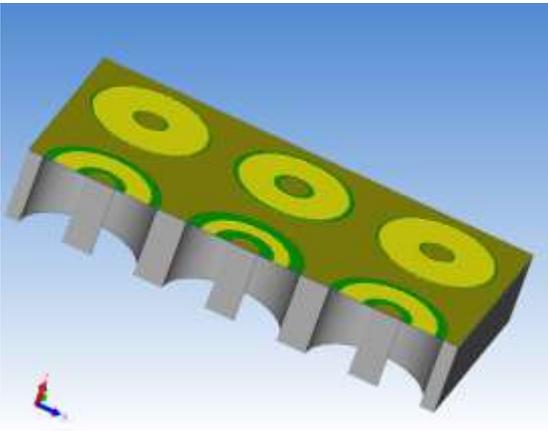
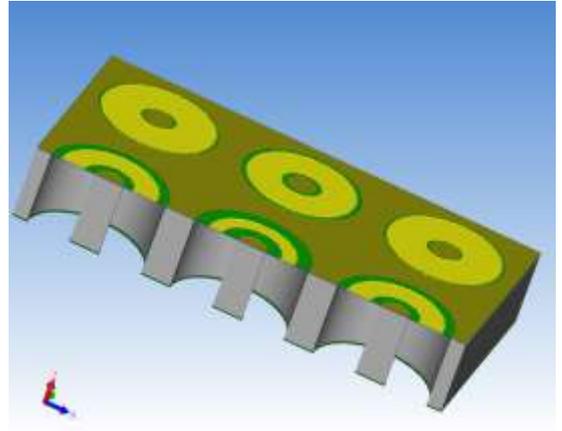
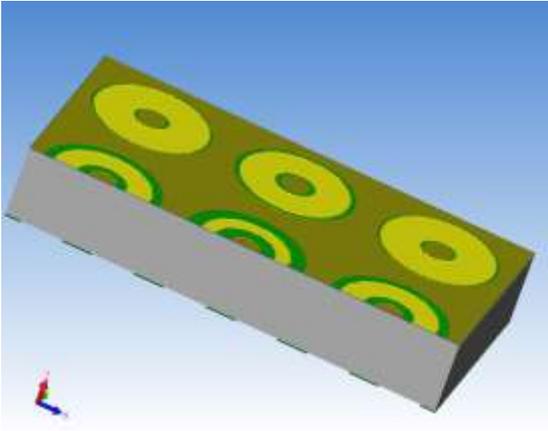
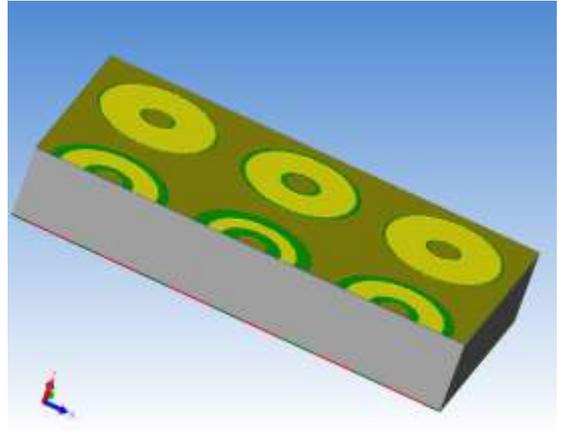
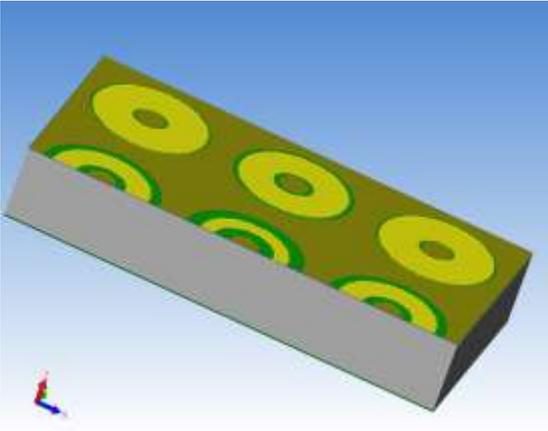
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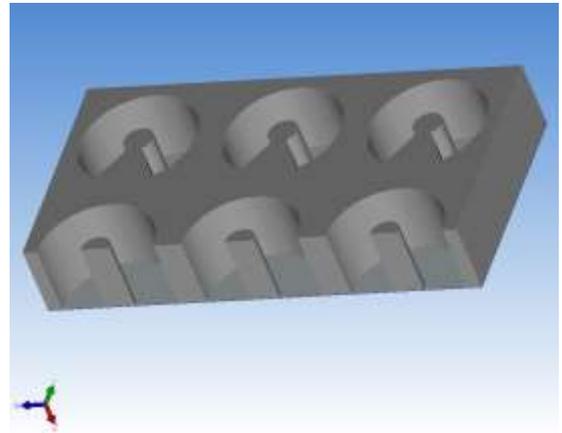
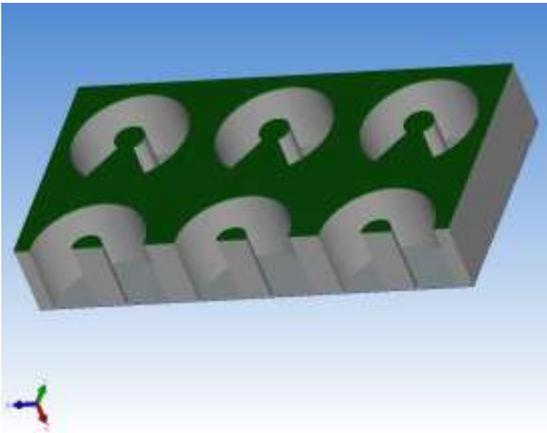
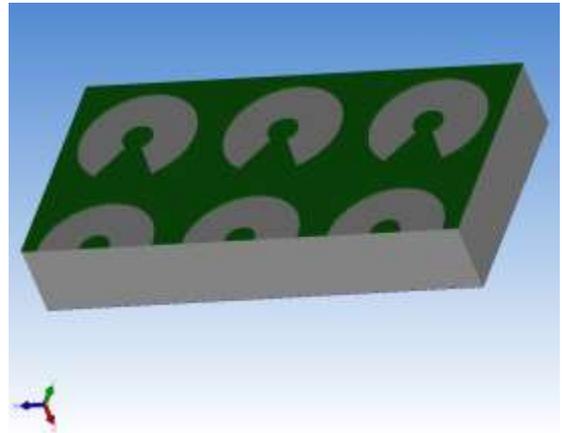
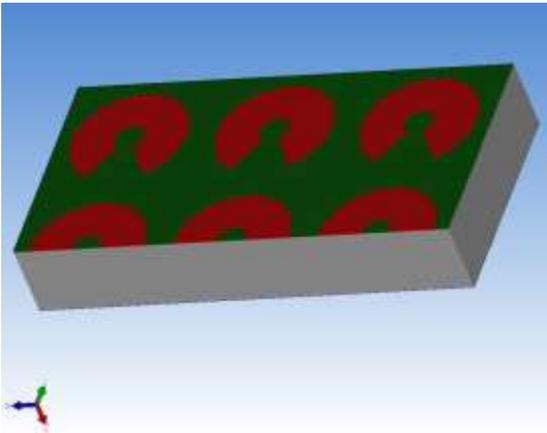
Stavíme ← Plánujeme → Vítame



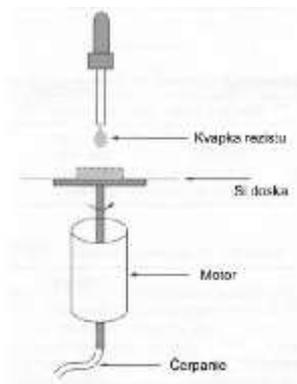






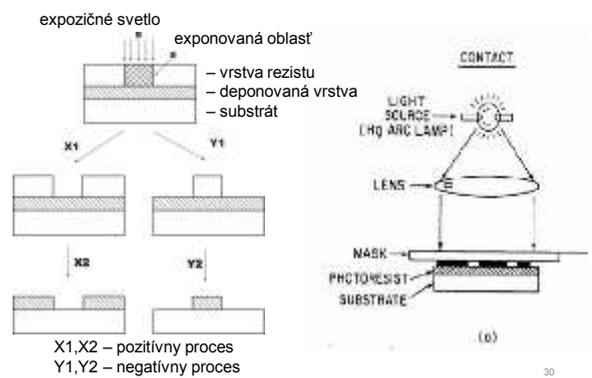


Nanášanie rezistu

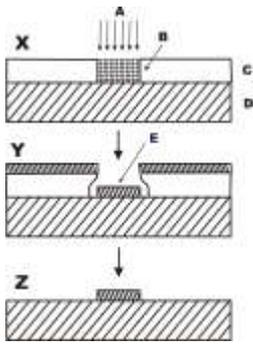


- A – odmastenie vzorky
 B – nanášanie rezistu s presnou hrúbkou
 C – vypekanie

Fotolitografia

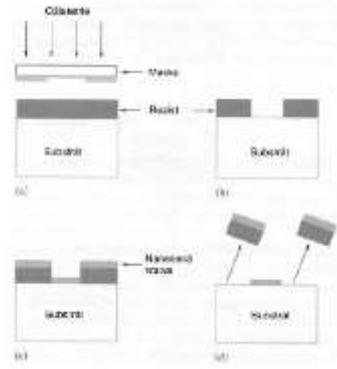


Technika „lift-off“



- A - expozičné svetlo
- B - exponovaná oblasť
- C - fotorezist
- D - substrát
- E - deponovaná vrstva

Technika „lift-off“



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1000 (US norma), 1000 častíc (< 0.5 μm) /stopa³ (ISO 5),
vlhkosť: 40 % ± 1 %, teplota: 22 °C ± 1 °C

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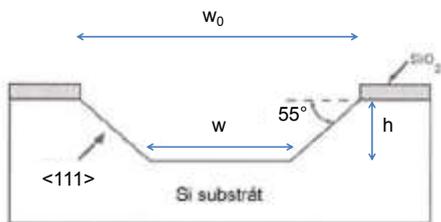
SÜSS MJB 21 Mask Aligner



SÜSS MJB 3 Mask Aligner

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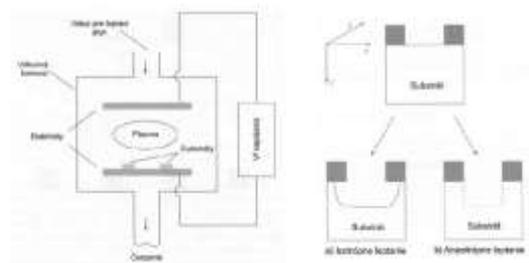
Mokrú leptanie



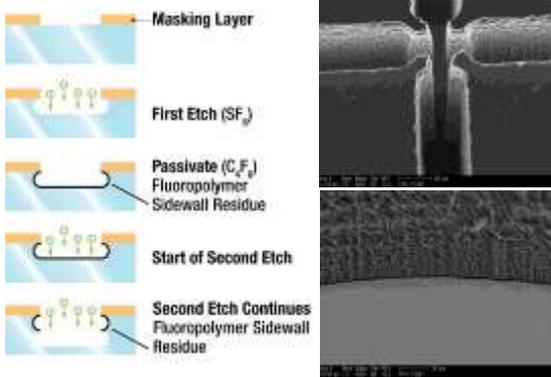
$$w = w_0 - 2h \coth(55^\circ) \quad \text{alebo} \quad w = w_0 - 1,4h$$

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

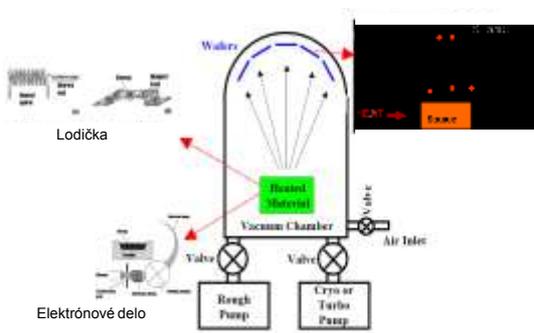
Suchú leptanie



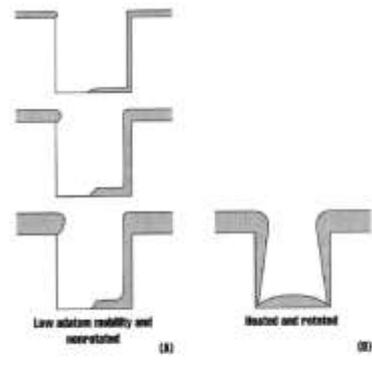
Bosch process



Naparovanie

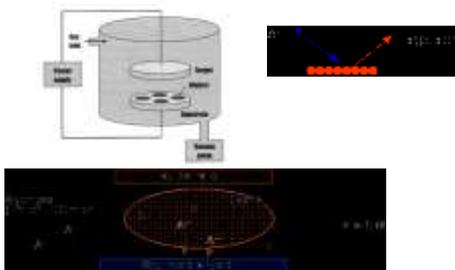


Naparovanie



Naprašovanie

Výhody: lepšie pokrytie, menšie radičné poškodenie, nanášanie zliatin
 Nevýhody: poškodenie spôsobené plazmou





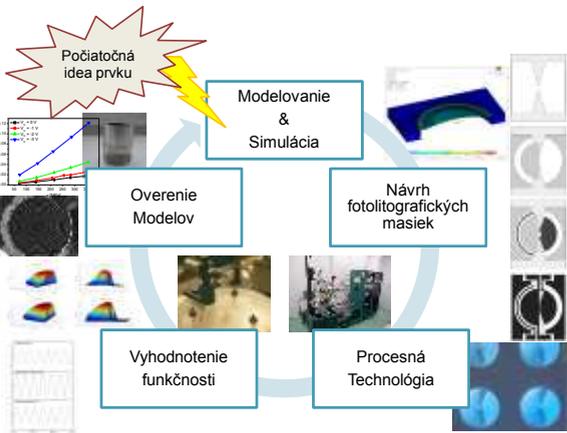
Naparovanie elektrónovým zväzkom



Naprašovanie

Tlakové MEMS senzory na EIÚ SAV

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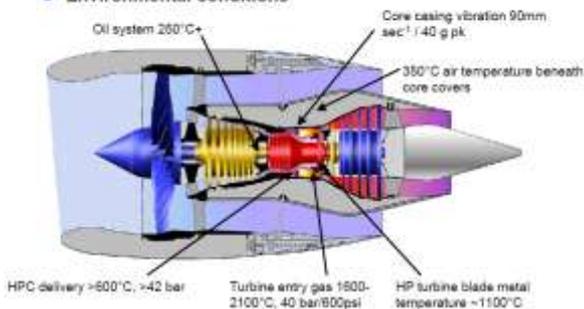
Využitie



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Three shaft civil turbofan

● Environmental conditions



Wireless Sensors - Motivation

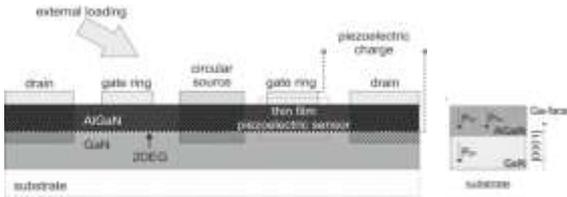
● Current state of the art

- 3000+ parameters measured on development engine
- Miles of sensor wiring
- Cables expensive, present risk of failure
- Cables tie engine modules together – difficult to dismantle engine in case of problem
- Build and test bed change can be long and expensive



● Wireless sensors enabling technology for cost savings

Princíp činnosti



Layers:

AlGaN 20 nm
GaN 4.2 μm
Si sub 350 μm

Ohmic:

Nb / Ti / Al / Ni / Au
20 / 20 / 120 / 40 / 70 nm

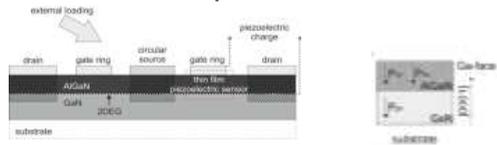
Schottky:

Ni / Au
40 / 120 nm

Top:

Ti / Au
30 / 120 nm

Princíp činnosti



$$Q = \int_{SV} DndA \quad D = eS + \epsilon E$$

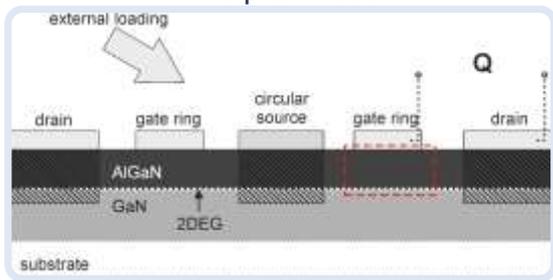
$$Q = \int D_3 dA = \int_0^{2\pi} \int_{R_1}^{R_2} \epsilon_{31} S_R r dr d\theta$$

$$-\frac{pR_C}{2t} = \sigma_0 + \sigma_p \quad R_C = \frac{d^2 + 4w^2}{8w}$$

$$Q = \frac{\pi(R_1^2 - R_2^2)\epsilon_{31}}{Y} \left(\frac{R_C}{2t} p - \sigma_0 \right)$$

Princíp činnosti

<BACK

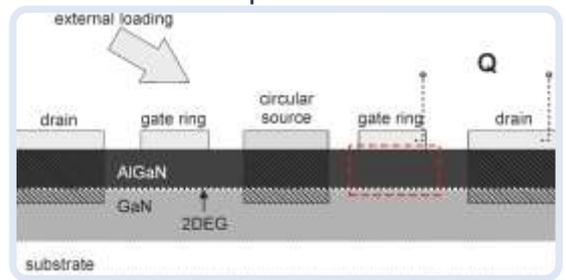


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Princíp činnosti

<BACK

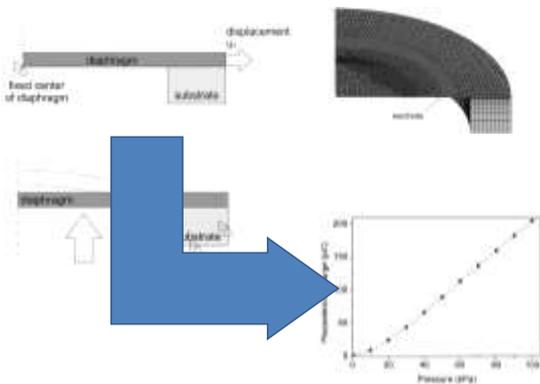


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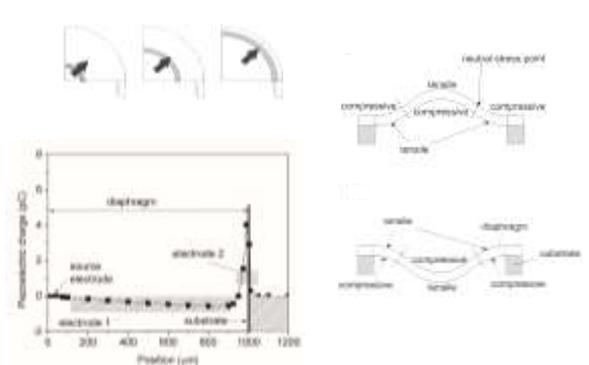
FEM model

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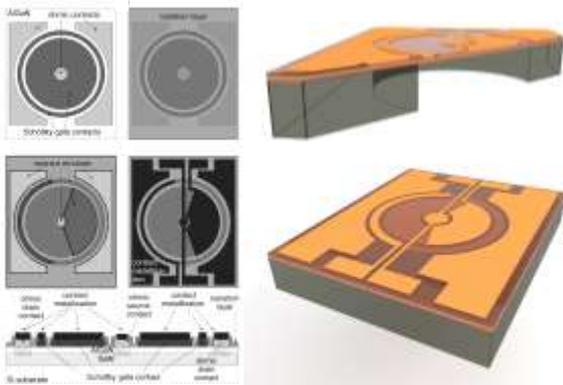
FEM model

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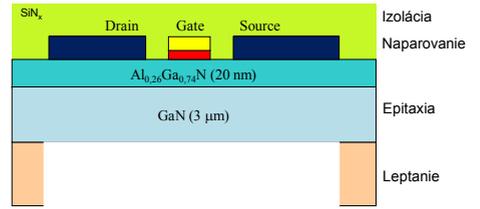


Layout

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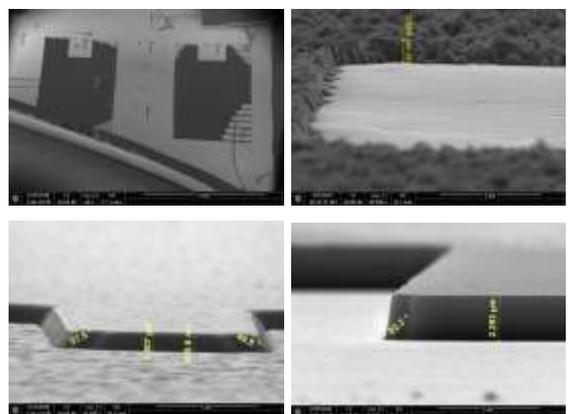
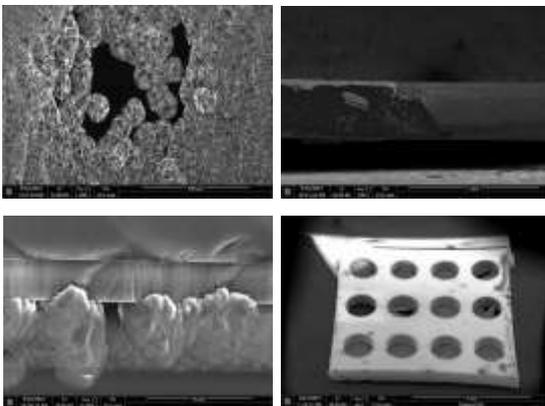
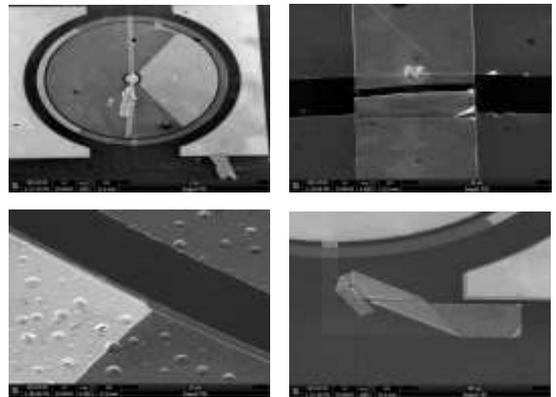
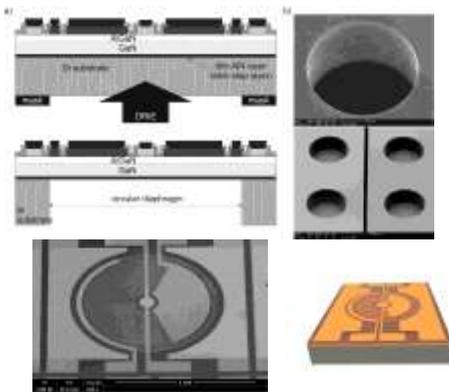
Procesná technológia



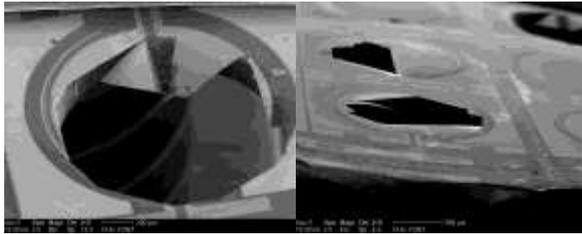
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Súčiastka

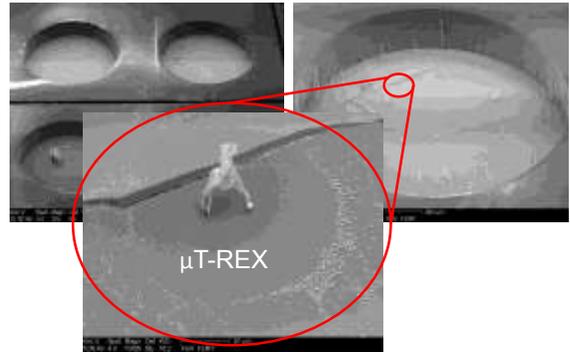
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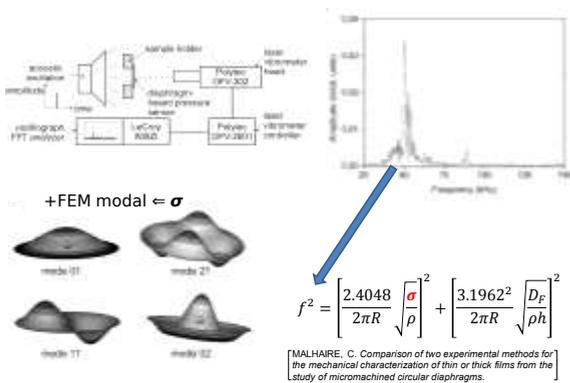
Praskanie membrán



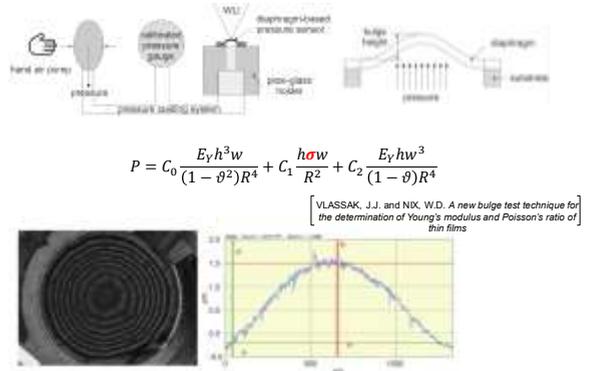
Praskanie membrán



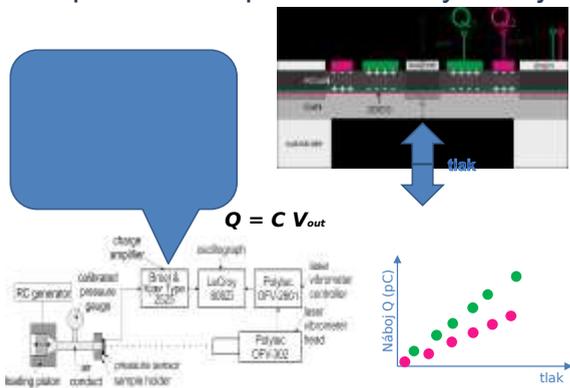
Experiment ⇒ σ (rezonančná metóda) ^{<BACK}



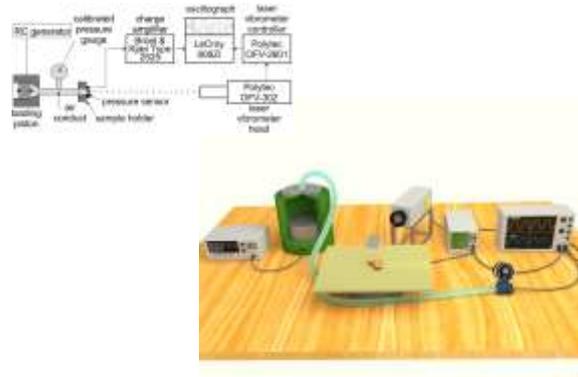
Experiment ⇒ σ (vychýľovacia metóda) ^{<BACK}



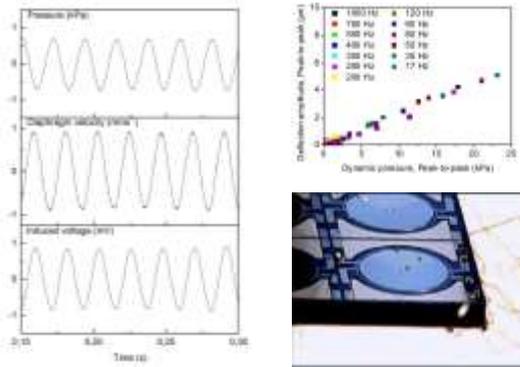
Experiment ⇒ piezoelektrický náboj ^{<BACK}



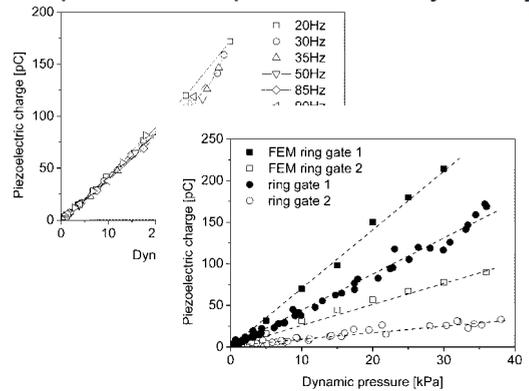
Experiment ⇒ piezoelektrický náboj



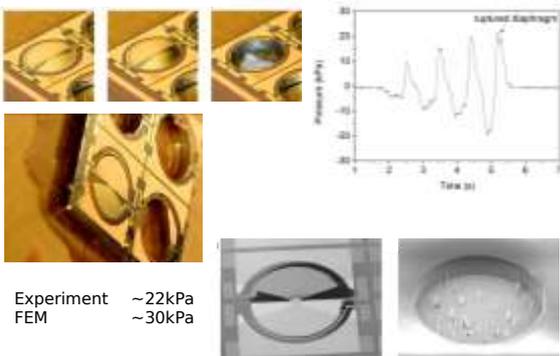
Experiment ⇒ piezoelektrický náboj <BACK



Experiment ⇒ piezoelektrický náboj



Experiment ⇒ kritický tlak <BACK

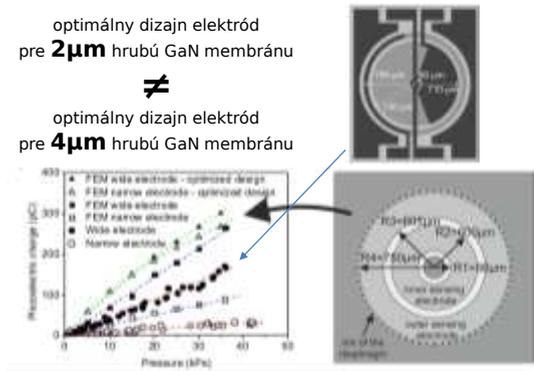


Optimalizácia elektród <BACK

optimálny dizajn elektród pre 2μm hrubú GaN membránu

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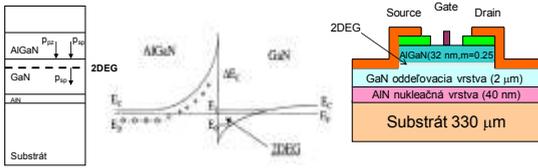
optimálny dizajn elektród pre 4μm hrubú GaN membránu



Ďalšie príklady

C-HEMT senzor

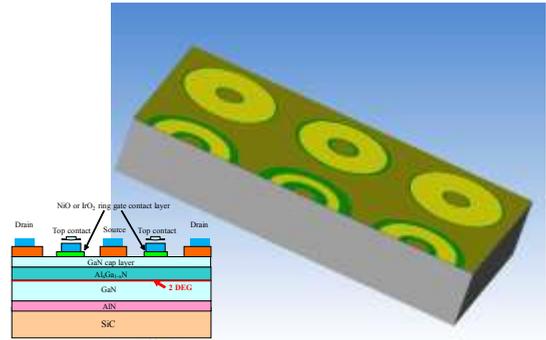
C-HEMT



- Spontánna a piezoelektrická polarizácia v napnutých vrstvách AlGaIn a GaN
- Elektróny zachytené vo forme 2DEG na rozhraní AlGaIn/GaN
- Zmena polarizácie v dôsledku pôsobenia externých síl
- Využitie pre konštrukciu tlakových senzorov

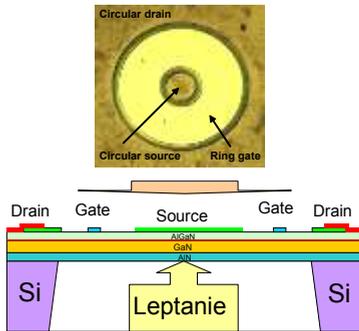
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C-HEMT

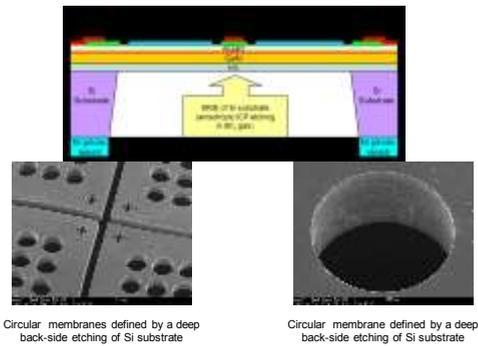


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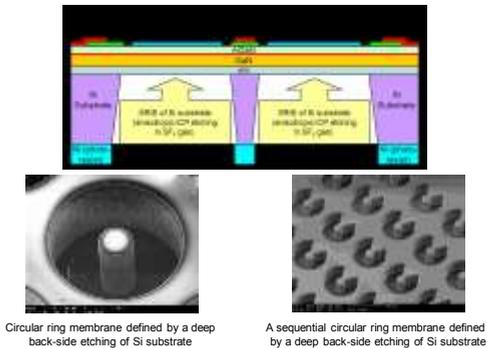
C-HEMT



C-HEMT



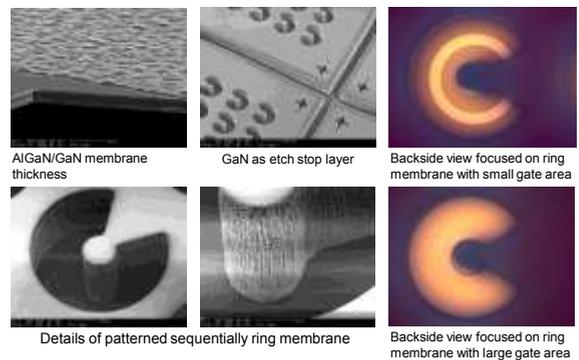
C-HEMT



Circular ring membrane defined by a deep back-side etching of Si substrate

A sequential circular ring membrane defined by a deep back-side etching of Si substrate

C-HEMT



AlGaIn/GaN membrane thickness

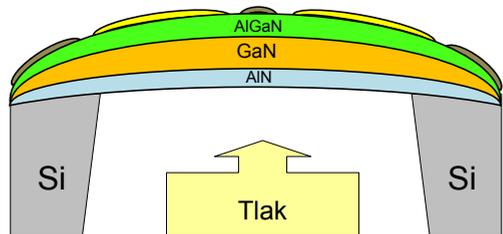
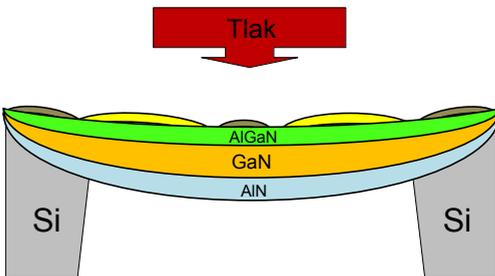
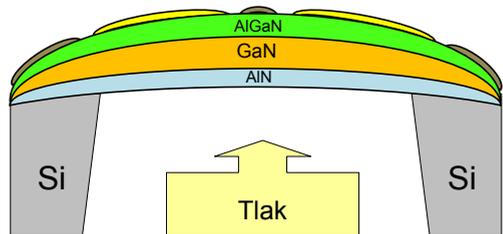
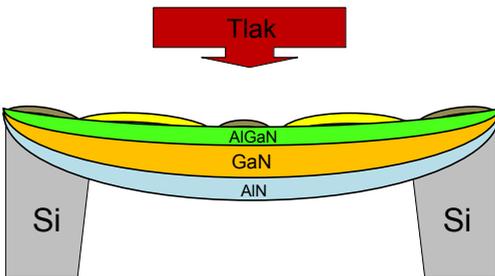
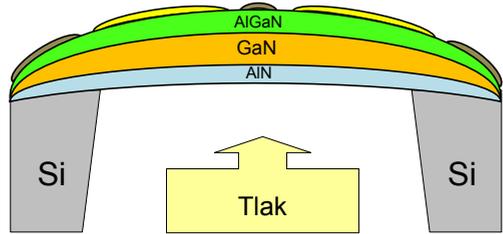
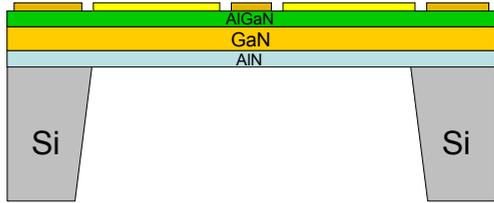
GaN as etch stop layer

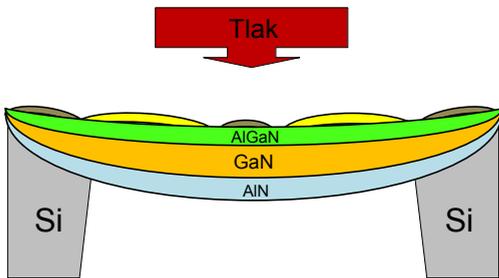
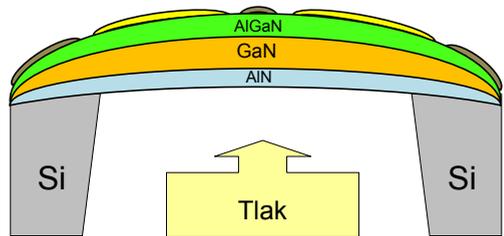
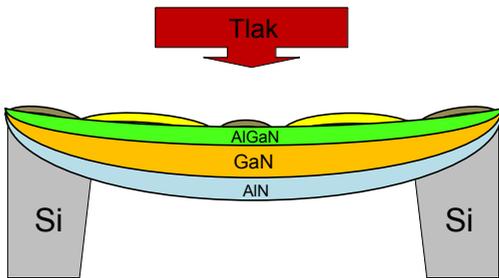
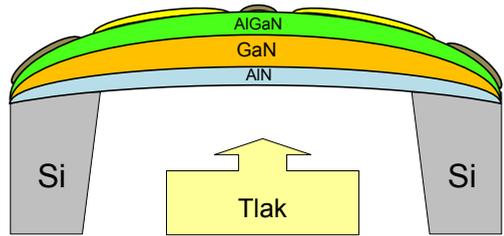
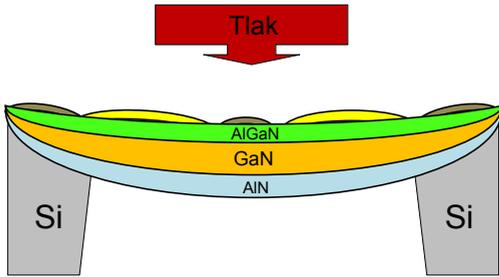
Backside view focused on ring membrane with small gate area

Details of patterned sequentially ring membrane

Backside view focused on ring membrane with large gate area

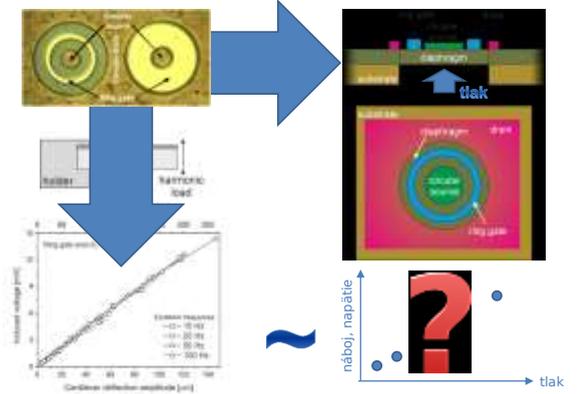
Drain Gate Source Gate Drain





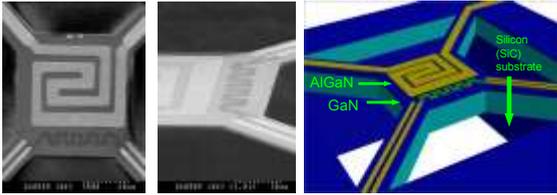
Návrh senzora

<BACK



Príklady

Mikrožiarič pre vodivostný typ plynového senzora

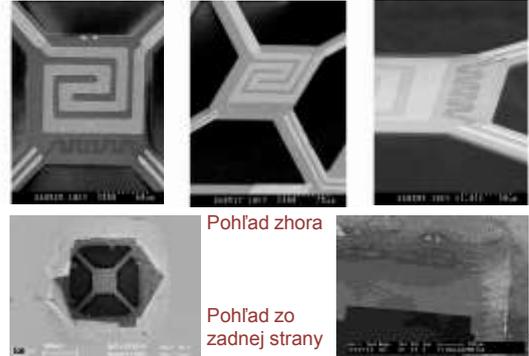


- Tepelná izolácia dosiahnutá pomocou AlGaIn/GaN membránovej štruktúry (využitie nižšej tepelnej vodivosti okolia)
- navrhnutá topológia s AlGaIn/GaN HEMT ako žiaričom a Schottkyho diódou vo funkcii teplotného senzora

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Príklady

Mikrožiarič a senzor



Pohľad zhora

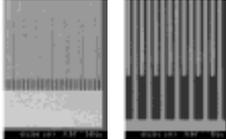
Pohľad zo zadnej strany

Príklady

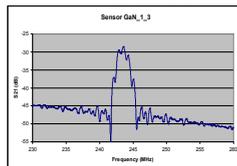
Chemický senzor s využitím povrchových akustických vln



Fotky z rastrovacieho mikroskopu



Prenosová charakteristika

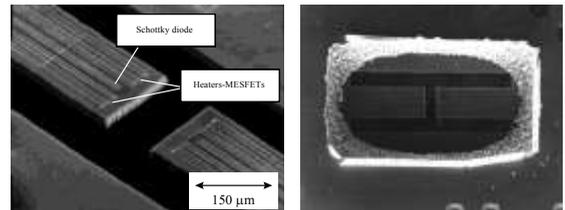


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Príklady

MEMS senzory RF výkonu

Po prvý krát predstavený MEMS senzor vysokofrekvenčného výkonu na báze GaAs nosníkov, využívajúci princíp elektro-tepelnej konverzie (meranie výkonu TV a rádio vysielačov)



MEMS senzor RF výkonu na báze GaAs nosníkov s hrúbkou 8 μm (pohľad z aktívnej strany)

Leptanie GaAs substrátu s hrúbkou ~ 300 μm zo zadnej strany

Puzdrenie

