UNIUNEA EUROPEANĂ

GUVERNUL ROMÂNIEI

INSTRUMENTE STRUCTURALE
2007-2013

Programul Operaţional Sectorial
"Creşterea Competitivităţii Economice"
"Investiţii pentru viitorul dumneavoastră"

Procese de depunere in sistemul Plasma Enhanced Chemical Vapor Deposition (PECVD)

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POS CCE: 665/12609/209/20.07.2010

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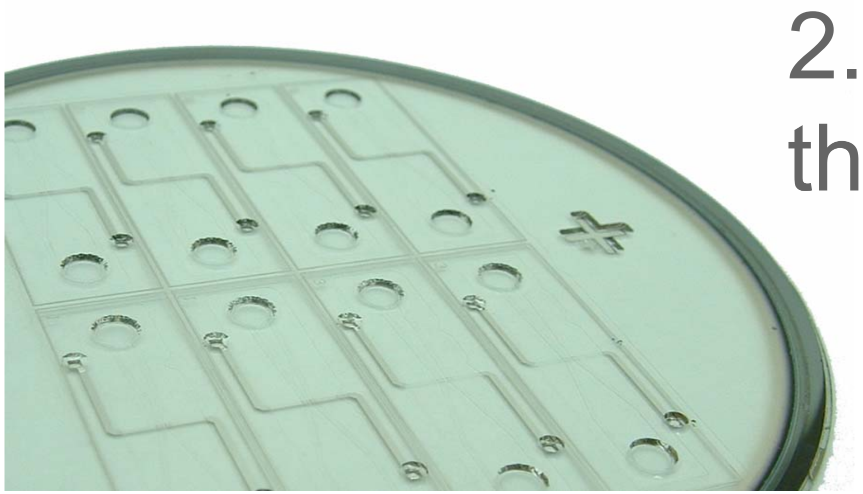
Scope

1. General presentation of:

-PECVD
-Deep RIE
-Wafer bonding



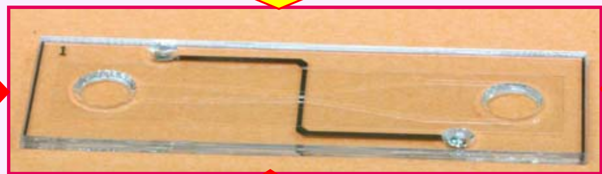
2. What can be done on these equipments?

Working principle !

- classical photolithographic process
-Deposition of the main metalic layers (Cr, Ti, Au, Ag, Al, Pt)
- thermal grow of SiO_2
- RIE patterning of SiO_2 Si_3N_4

Standard microfabrication processes

Wet etching through Pyrex glass



Photolithography on nonplanar surface

Adhesive wafer-to-wafer bonding

- **TECHNOLOGIES:**
  - Thin film depositions in PECVD reactor
  - Wet etching of glass
  - Adhesive bonding techniques
  - Micropatternining over nonplanar surfaces
  - Hot embossing

- **DEVICES:**
  - Dielectrophoretic chips
  - Electrical impedance spectroscopy for biological samples
  - Microneedles for transdermal drug delivery
  - Cell therapy using microneedles array
  - Cell culture on MEMS platforms
  - Tissue reconstruction using microfluidics

PECVD – Thin films with low residual stress

- Low stress SiN :
  - deposition rate = 320nm/min
  - Applications: silicon membrane for cell culture (porous) (S. Zhang et al, Biomaterials, 2011)
  - Cantilevers (AFM tips), membranes

- Low stress a:SiC : deposition rate =180 nm/min
  - Cell culture
  - Microfluidics / nanofluidics on IC

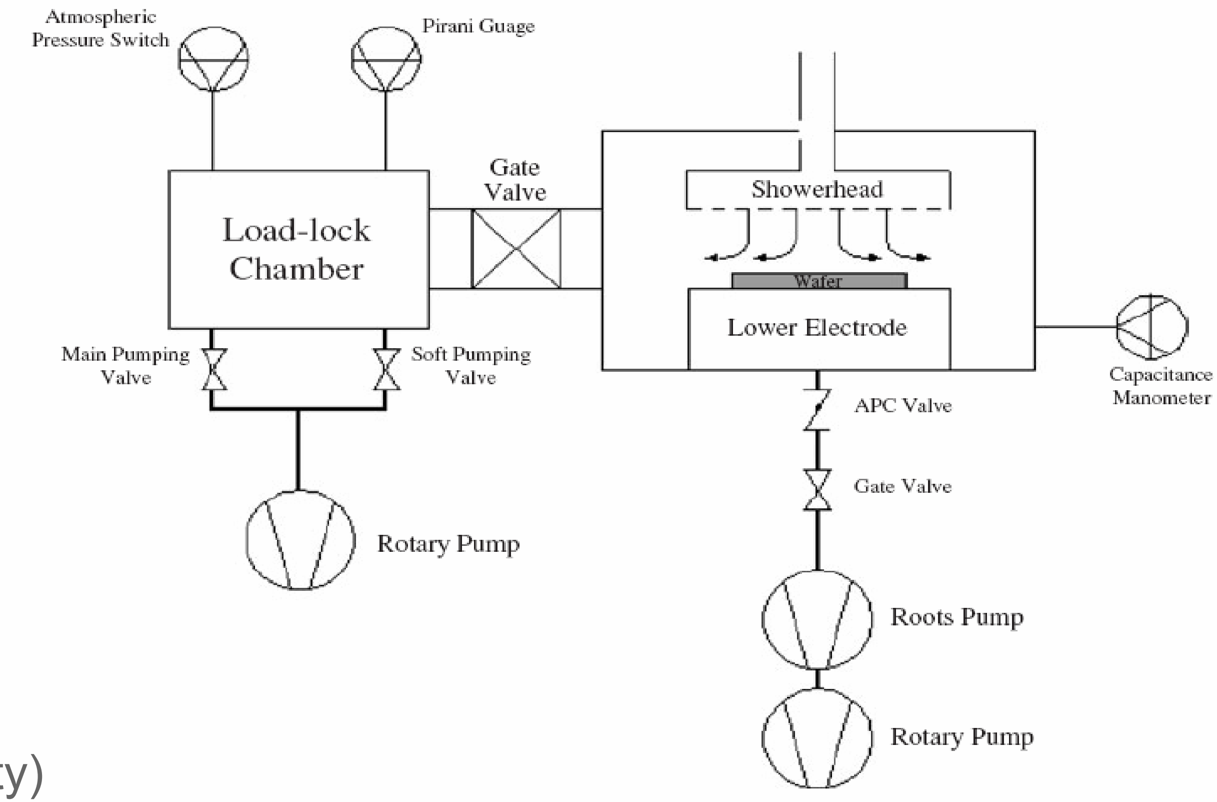
- Amorphous silicon =100nm/min…. Deposition up to 20um-thick
- (very important sacrificial layer for surface micromachining)
- TEOS
- SiO2 deposition (deposition rate 400nm/min)

Short description of PECVD equipment

Equipment: PECVD (Plasma Enhanced Chemical Vapor Deposition)- STS

Main process parameter :

-Deposition temperature: 200-400 ^{o}C
-pressure: 450 ~ 1400 mTorr
-Power: 20 W ~ 600 W/ 20-100W
(RF power at 13.56 MHz/380KHz)
-Precursors: specific for: SiN, SiC, aSi, SiO2, TEOS (LDS), SiNxOy



Important features:

-dual frequencies (stress control)
-showerhead (uniformity)
-heated chamber (deposition quality)

Very important aspect: Plasma cleaning (C4F8/O2) after each 6um-thick deposition

Short description of PECVD equipment

Equipment: PECVD (Plasma Enhanced Chemical Vapor Deposition)- STS

Gas precursors:

- SiNx: SiH4 (pure) / NH3/ N2
- SiC: SiH4 (pure) / CH4
- aSi : SiH4 (pure) / Ar
- SiO2: SiH4 (pure) / N2O/ Ar
- TEOS (LDS): TEOS/ O2
- SiNxOy: SiH4 (pure) / NH3/ N2O

Literature:

SiN

C. Iliescu, F.E.H. Tay and J. Wei, “Low stress and high deposition rate of PECVD - SiN_x layers using high power and high frequency for MEMS applications,” *Journal of Micromechanics and Microengineering*, **vol. 16, no. 4,**, pp. 869-874, April 2006

SiC

C. Iliescu, B.T. Chen, D.P. Poenar and Y.Y. Lee, “PECVD amorphous Silicon Carbide membranes for cell culturing,” *Sensors and Actuators B,* **vol. 129, issue 1**, pp. 404-411. 2008,

a:SiC

C. Iliescu and B.T. Chen, “Thick and low stress PECVD amorphous silicon for MEMS applications,” *Journal of Micromechanics and Microengineering,* **vol. 18, no. 1,** pp. 15024, 2008

SiNx: Influence of the RF frequency mode

Most commonly used method to reduce residual stress

Mixed frequency deposition method

Apply high frequency power and low frequency power alternatively

High frequency: generate reactive species and provide electrons and ions

+

Low frequency: control ion bombadment to densify the layer and change stress from tensile to compressive

Tensile stress from HF can be compensated by compressive stress from LF to produce low stress

At 13.56MHz, ions do not respond to RF field

At 380kHz, ions can respond and give ion bombardment of growing film

Mixing of High and Low frequency power allows control over ion bombardment and hence control over film stress and film density

DISADVANTAGE:

To achieve homogenous layer, the thickness of each layer must be as thin as possible

LOW DEPOSITION RATES

STRESS GRADIENT

Influence of the RF Power

Fabrication of low stress SiNx layers

New method to produce low residual stress with high deposition rate → Deposit at high power in HF mode

Higher Power ↑ → Dissociation rate of gas ↑ (especially more N_2)

↓

More N^+ species ↑

compressive stress due to the volume expansion of the SiNx film

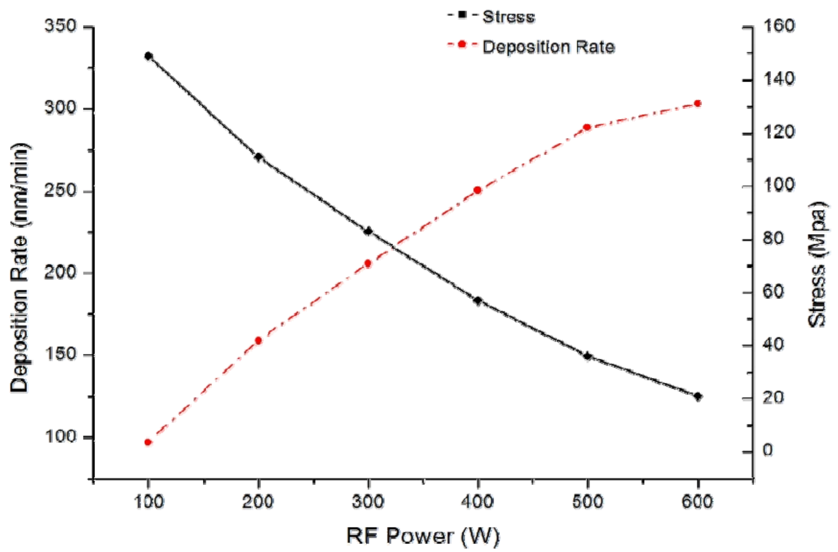
← Incorporation of N bonding ↑

↓

Compensation to tensile ↑ stress of the whole wafer

↓

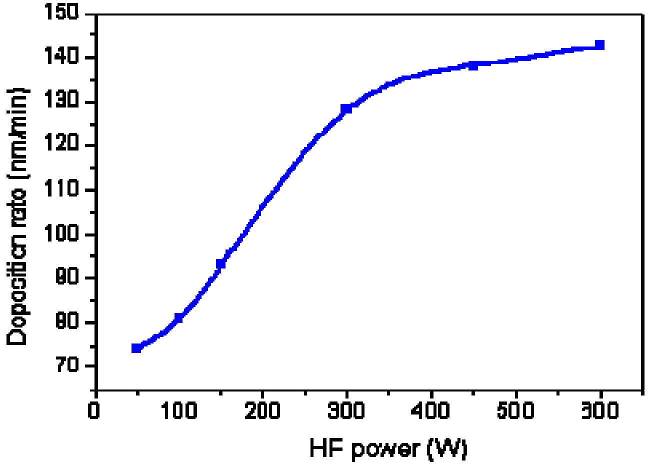
Lower Stress ↓ (Tensile)



Pressure: 900mTorr;
SiH_4/ NH_3/ N_2 = 100/60/1500 sccm

Influence of the RF Power (HF Mode)

Fabrication of low stress α-SiC layers



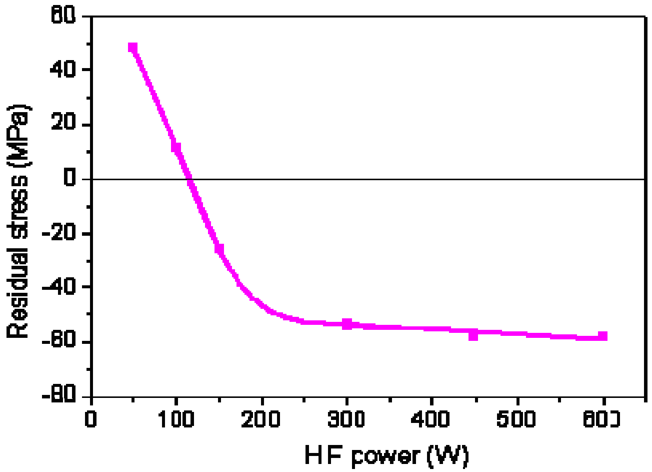
High Power → High Dissociation rate of reactant gas → High Deposition rate

High Power → More kinetic energy for molecular migration

Stronger molecular movement during film growth

Improve film structure

Lower Stress

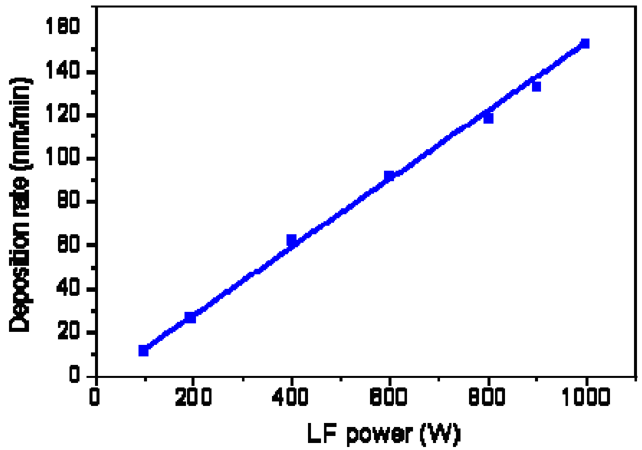


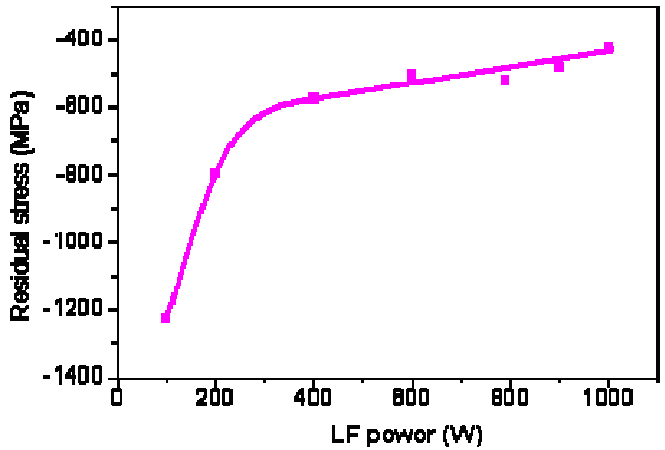
Higher power brings too much reactive species and reduces the mobility.

A low stress a-SiC was obtained to deposition at 150W, HF-mode

Influence of the RF Power (LF Mode)

Fabrication of low stress α-SiC layers





Under same RF power, the HF mode generated higher deposition rate than LF mode.

In HF mode, only electrons follow the RF field. Ions stay still due to their heavier mass

In LF mode, ions move and ion bombardment is higher and dominate the process

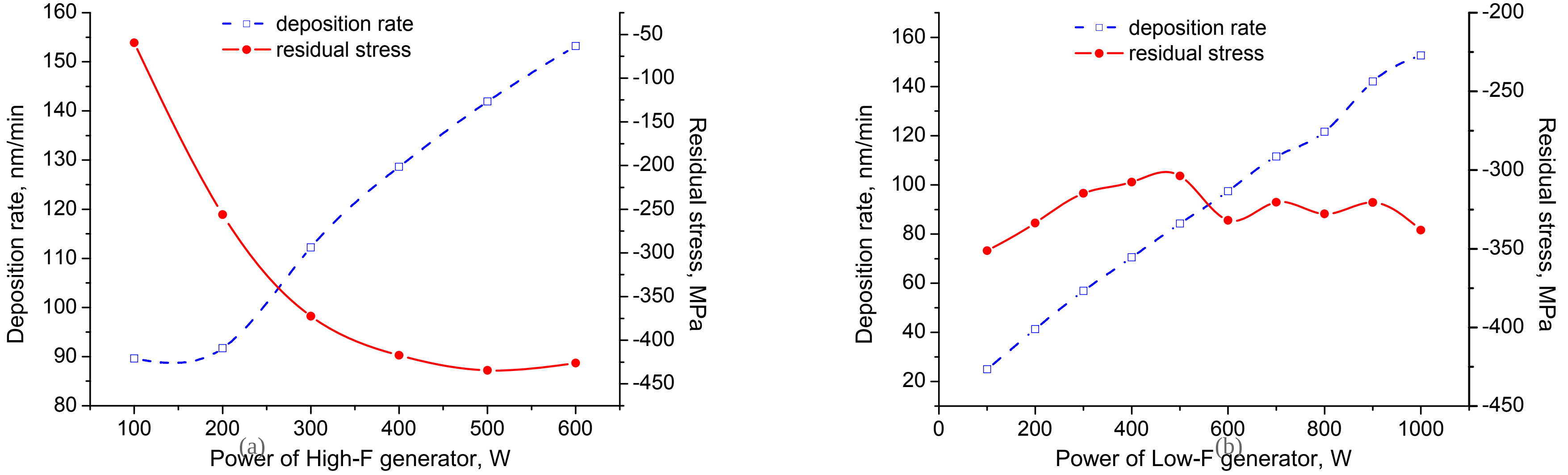
High Power ⟶ **Stronger ion bombardment**

⇓

Lower Stress ⟵ **Higher densification of the layer**

Influence of the RF Power

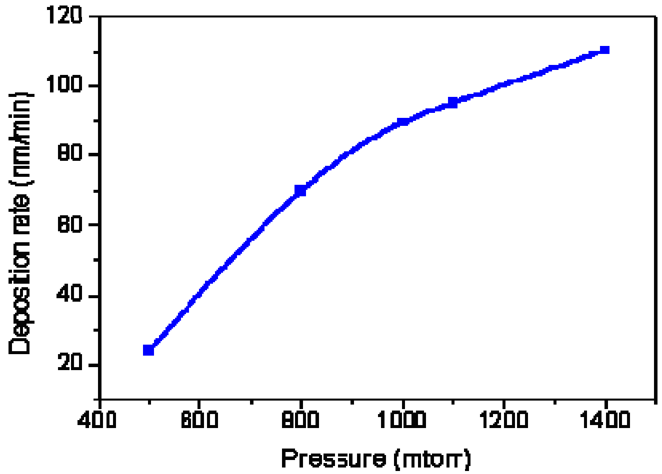
Fabrication of low stress a-Si:H layers



- A high power is associated with a high rate of gas dissociation, leading to a high deposition rate (for both generator frequency)
- The residual stress increases with the power increasing (high-F mode)
- No significant change of stress for the power variation (low-F mode) due to ion bombardment and densification effect at low frequency

Influence of the pressure

Fabrication of low stress α-SiC layers



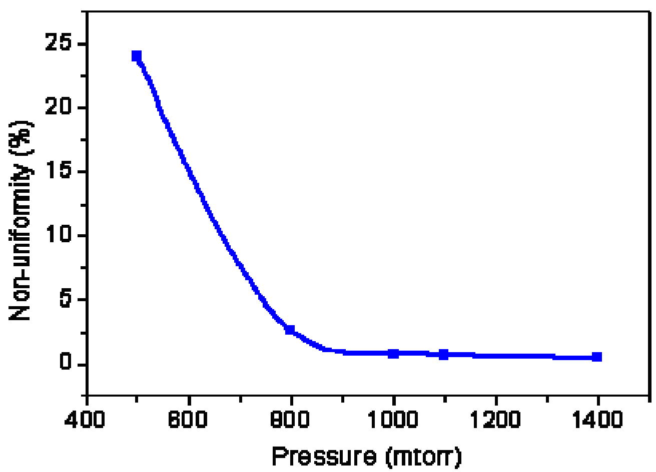
Power: 150 W/HF mode; Temperature: 300 °C
Pressure: 500~1400mTorr; SiH_4: 45 sccm
CH_4: 300 sccm; Ar: 700 sccm

Low Pressure → Low concentration of reactive species

↓

Low Deposition rate

From 900 to 1400 mTorr → Good Uniformity



Low Pressure → High Pumping Speed

↓

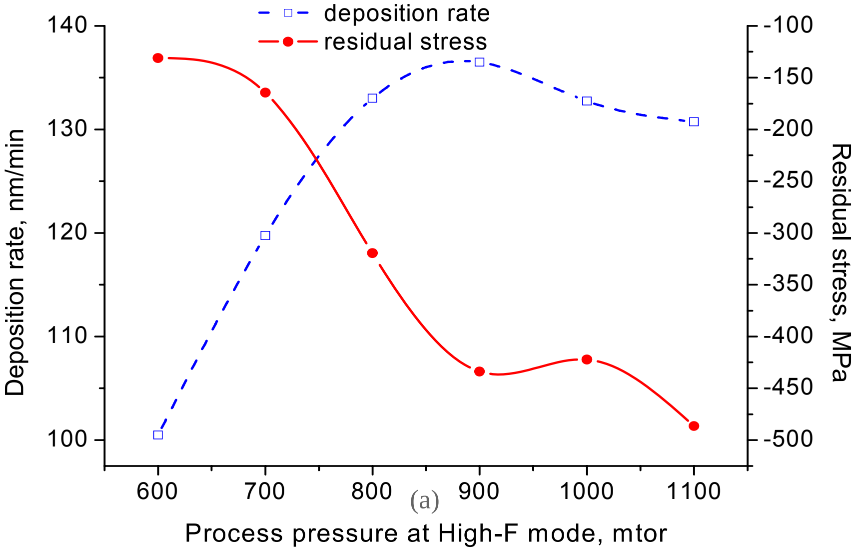
High velocity of gas & Gas molecules concentrate at the edge of wafer

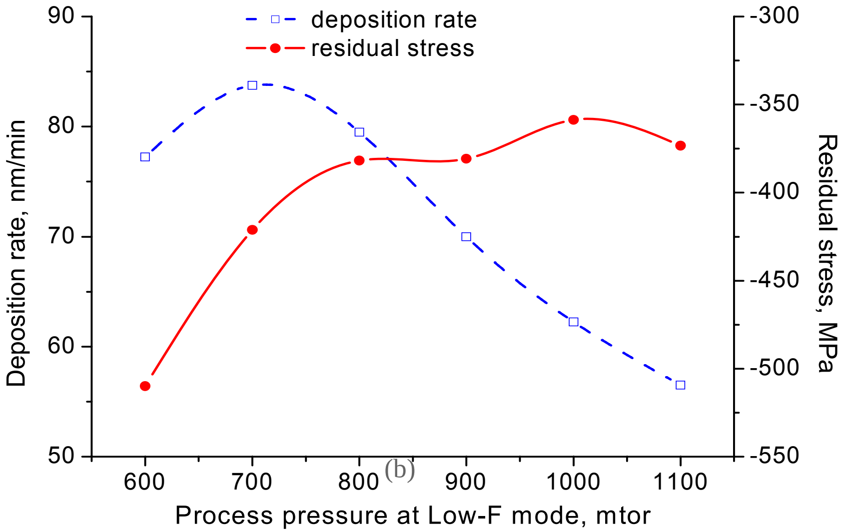
→ Thicker layer at the edge and thinner in the center

BAD UNIFORMITY

Influence of the pressure

Fabrication of low stress a-Si:H layers



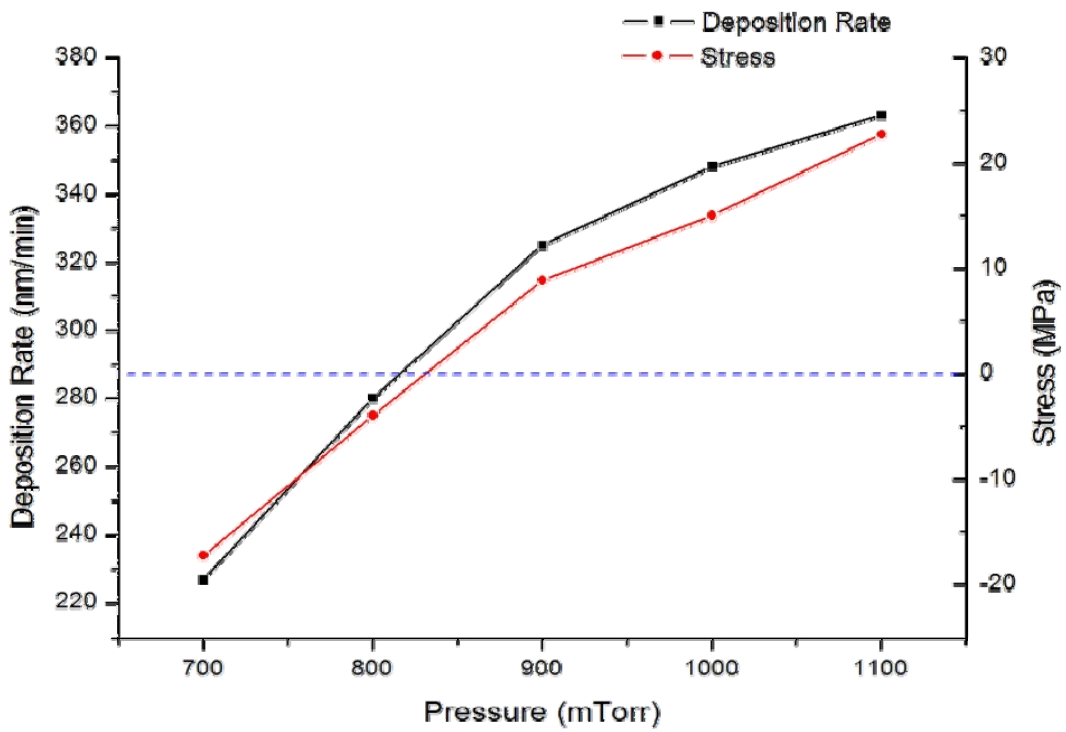


- ❑**High pressure** → increased collisions of reactant gases, charges and energetic species → **high deposition rate and high film compressive stress (at HF mode).**

- ❑**Lower pressure** → **generates relative higher deposition rate and low stress (at LF mode)**

Influence of the pressure

Fabrication of low stress SiNx layers



Power: 600 W
Pressure: 700~1100mTorr;
SiH_4: 120 sccm
NH_3: 75 sccm
N_2: 1150 sccm

Pressure ↓

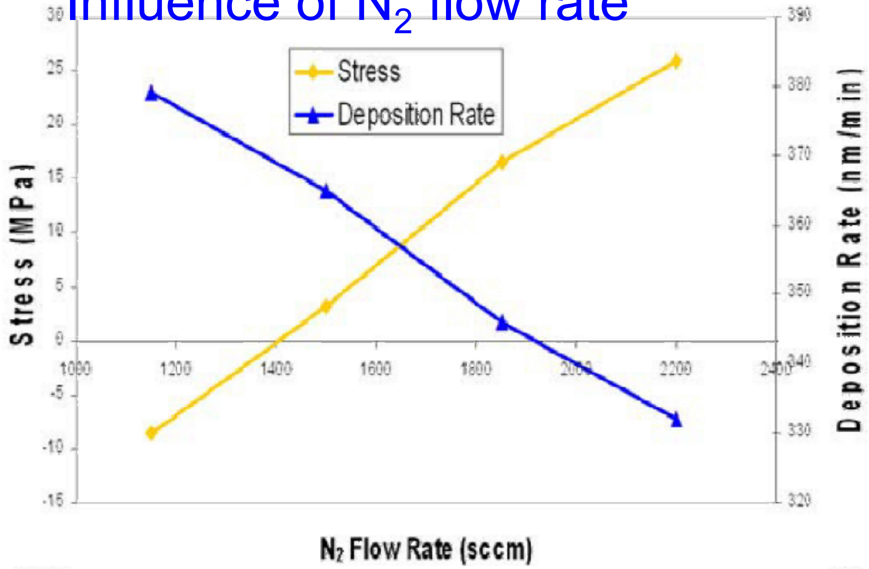
Electron energy ↑

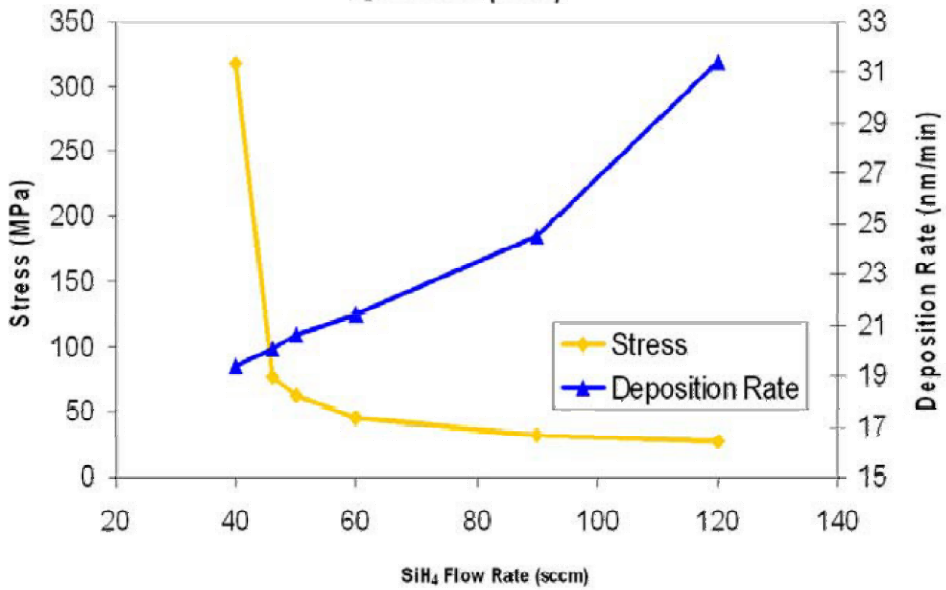
Si/N ratio ↓

Can be used for the fine tunning of residual stress !

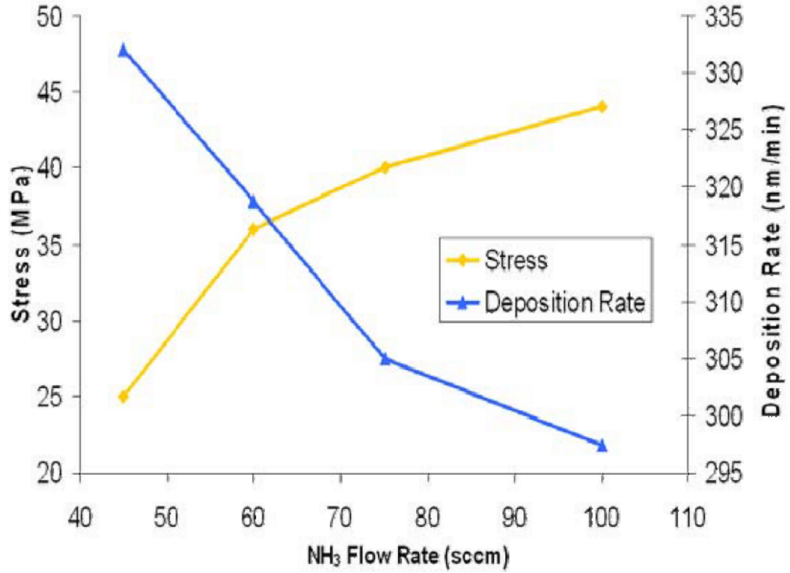
Influence of the flow rates

Influence of N_2 flow rate





Influence of SiH_4 flow rate



Influence of NH_3 flow rate

TEOS- RESULTS

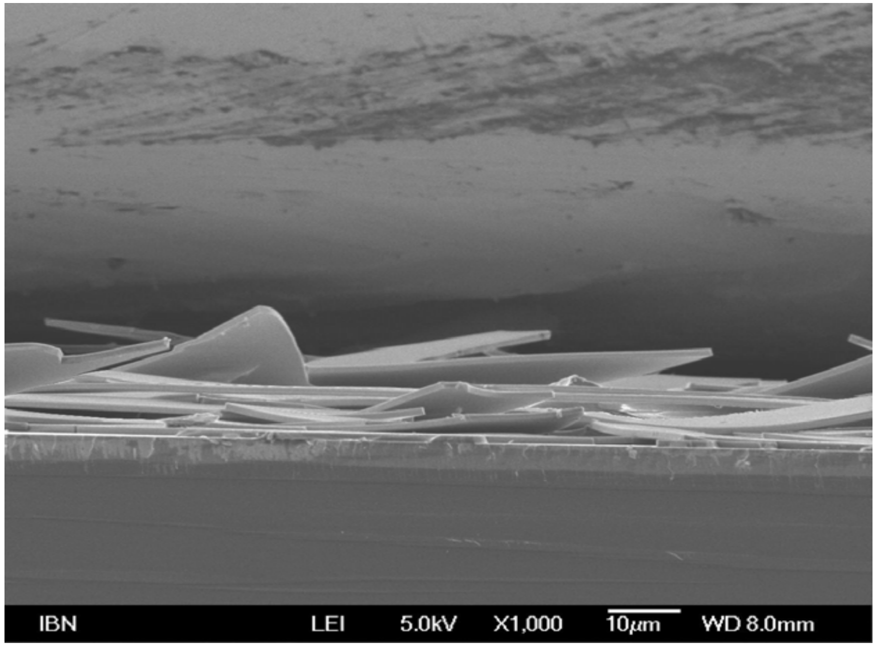
Process parameters		Deposition rate	Uniformity	Stress
Pressure ↑		↑	Better	More tensile
HF Power ↑		↑	Better	More compressive
LF Power↑		Insignificant	Insignificant	More compressive
TEOS flow rate↑		↑	Insignificant	More tensile
Temperature↑		↓	Insignificant	More compressive

Refractive Index fairly constant at 1.44-1.46.

Limitations- TEOS

Films damaged at

- High pressures
- Low O2/TEOS flow ratio
- Low temperatures



Applications: SiNx layers

Fine tuning of SiNx residual stress

Deposition temperature: 300 ^{o}C

Chamber pressure: 850 mTorr

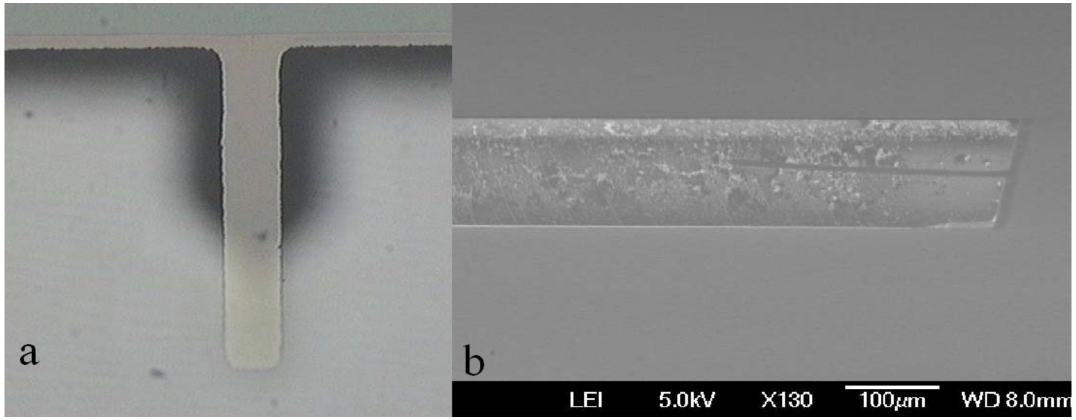
Power: 600 W

Precursors: N_2 : 1200 sccm
SiH_4: 120 sccm
NH_3 : 75 sccm

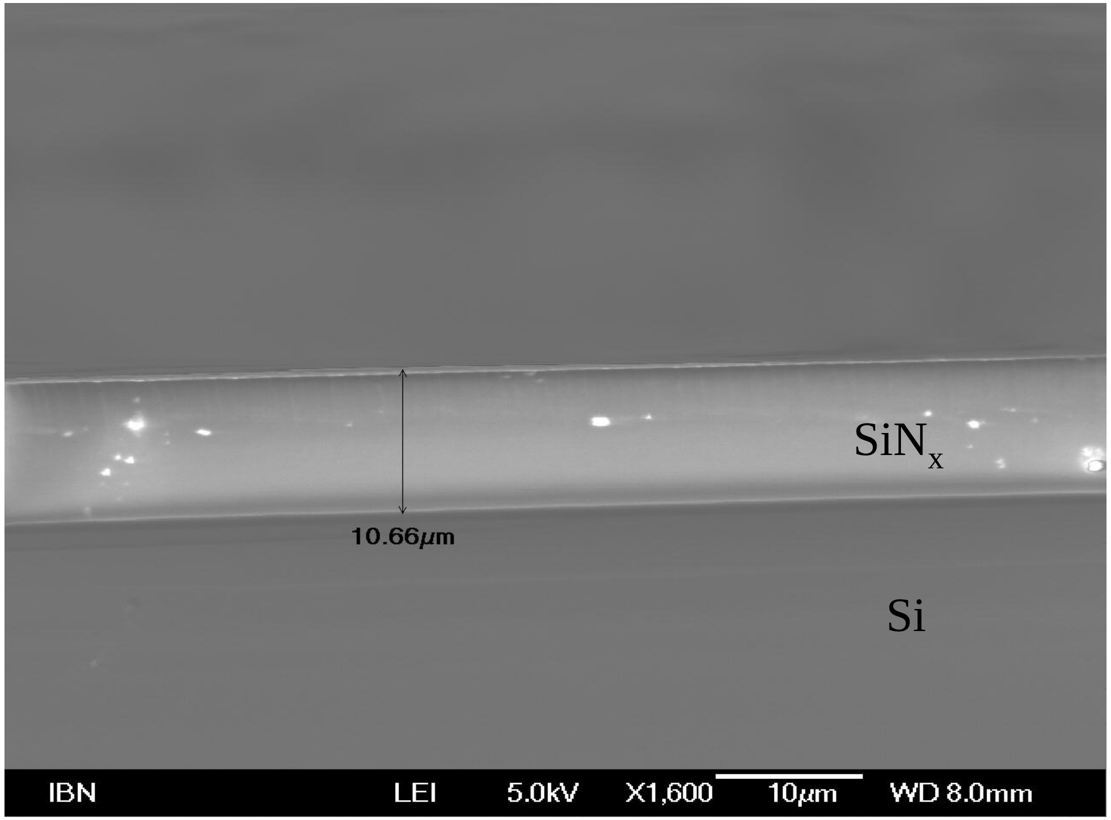
RF mode:HF

Residual Stress: 4 MPa

Deposition Rate: 320 nm/min



Thick SiNx layer with low stress



Thick layer

↓

Larger surface

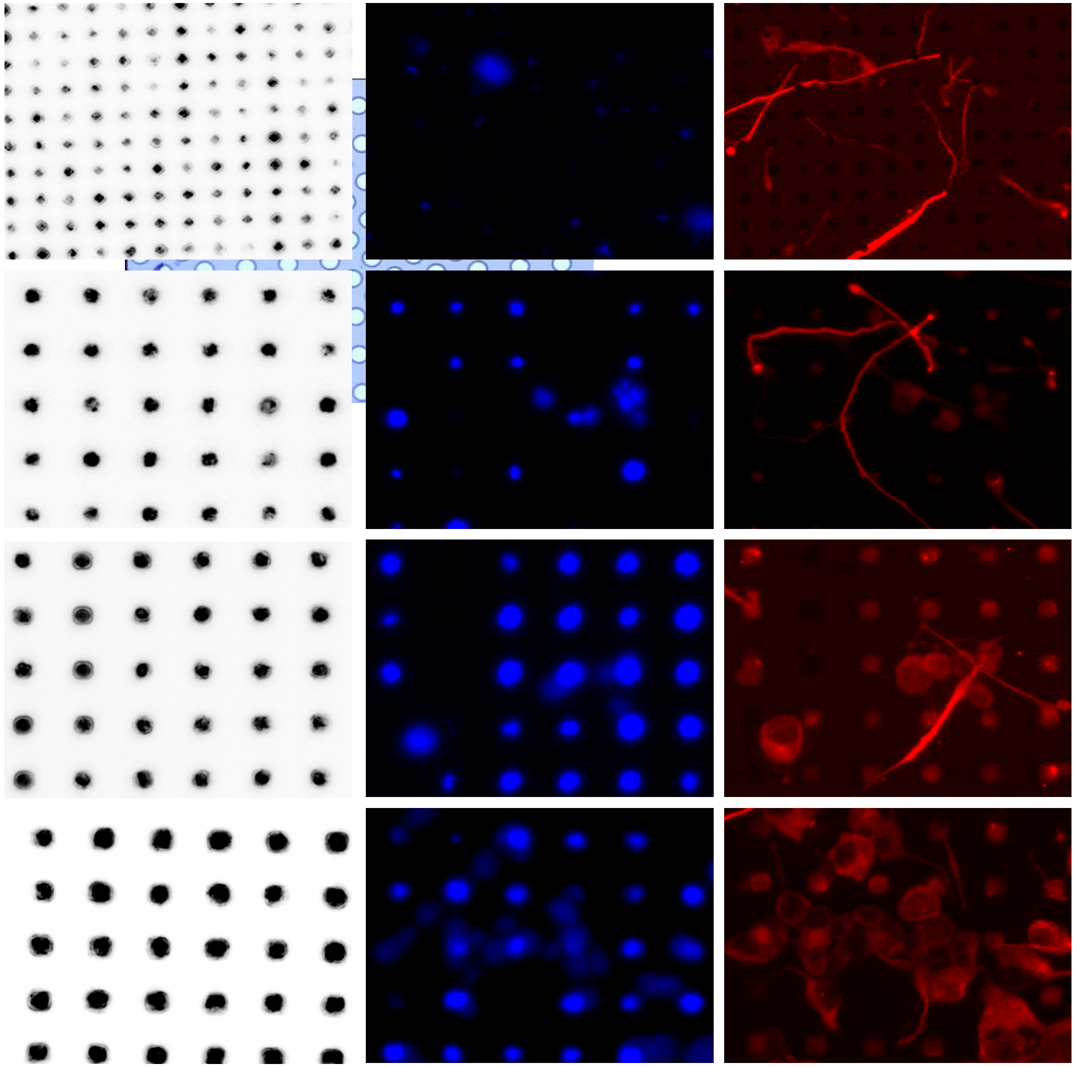
↓

Better for cell propagation

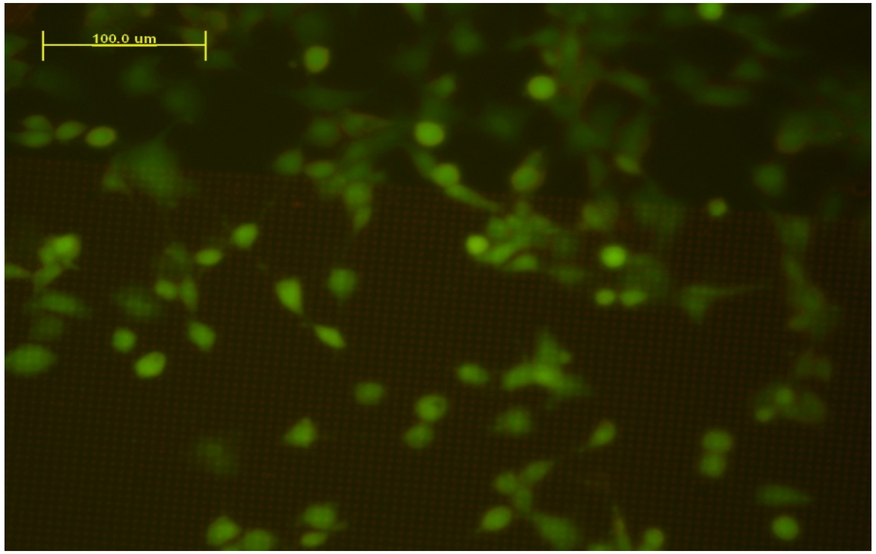
Easy for cleaning and dicing

Deposited in
ONLY 40 minutes !!

SiNx Membrane for Cell Culture



SiNx membranes
for Neuronal Cell Culture

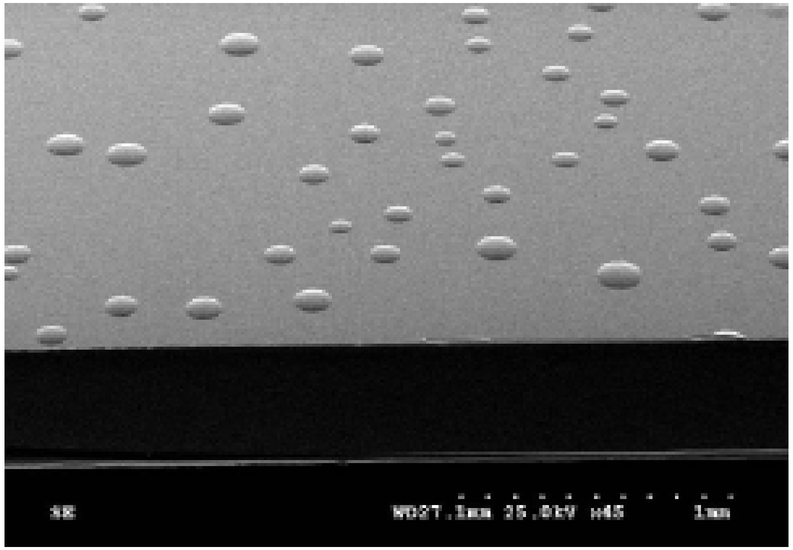


Cell line: mouse D1 mesenchymal stem cells

Process: Stained with the cell tracker dye for twenty-four hours

ADHERE strongly onto the nanoporous SiNx membrane

Problems associated with the deposition of a:Si

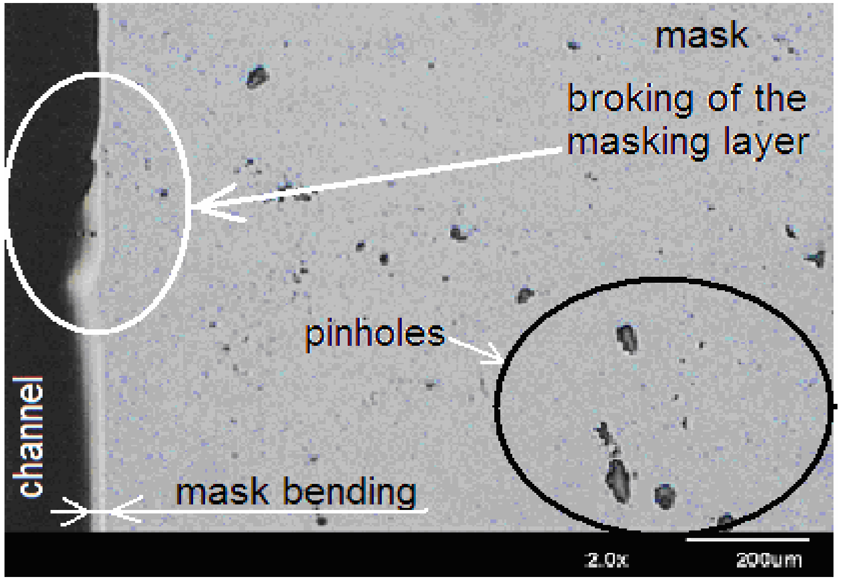


Hillocks defects on 2μm film

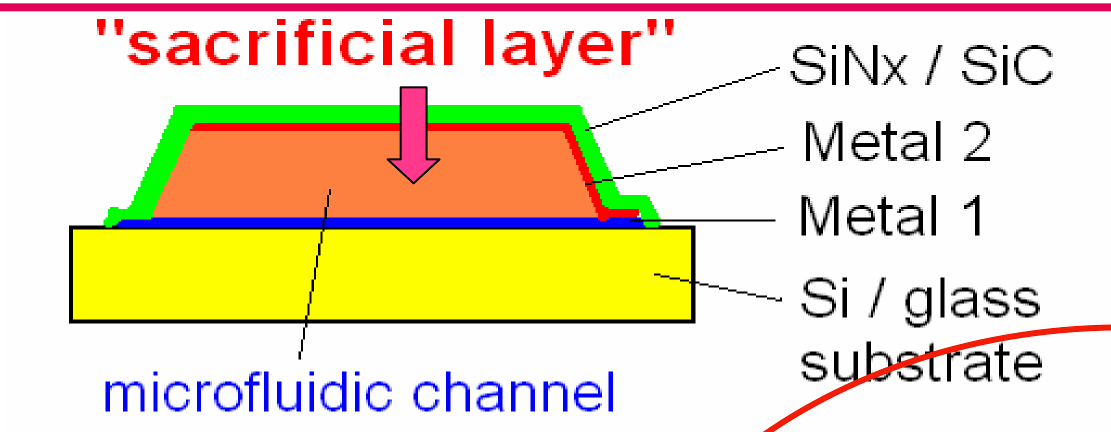
Chung, C. K. et al, “Fabrication and characterization of amorphous Si films by PECVD for MEMS,” J. Micromech. Microeng. 15, 136–142 (2005).

Defect generation during wet etching of glass

Iliescu, C. et al, “Stress control in masking layers for deep wet micromachining of Pyrex glass,” Sens Actu. A 117, 286–292 (2005).



“Thick sacrificial layer” for microfluidics on IC



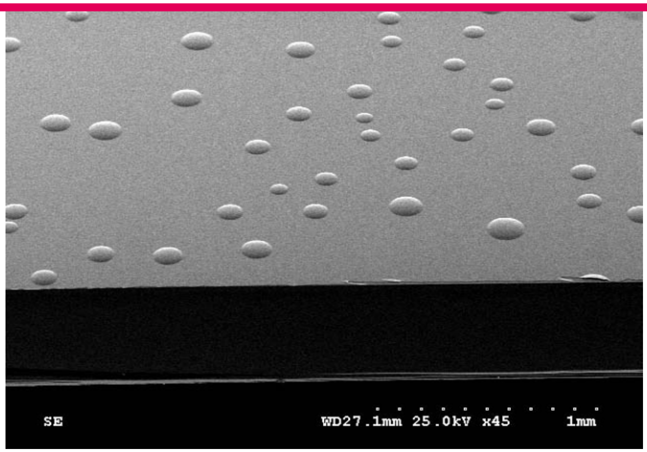
SiO_2 (PECVD)

- Can be deposited in thick layers ~ 20um (with a good deposition rate)
- Removing in HF
- Metal layers can be affected during etching
- Difficult to be pattern in thick layers (in the context of the design fabrication process)

Amorphous Si

- Only thin layer can be deposited (max reported 2um) and relatively slow deposition rate
- Removing in wet solutions (alkaline: KOH, EDP, THAH) or dry etch (XeF2)
- Selectivity of the etching process is quite good
- Easy patterning for thick layer

Thick amorphous Si layer



Thick amorphous Si films

- Problems related adhesion of the film and "hillocks"

Chung C K, et al, 2005
J. Micromech. Microeng. **15** 136–42

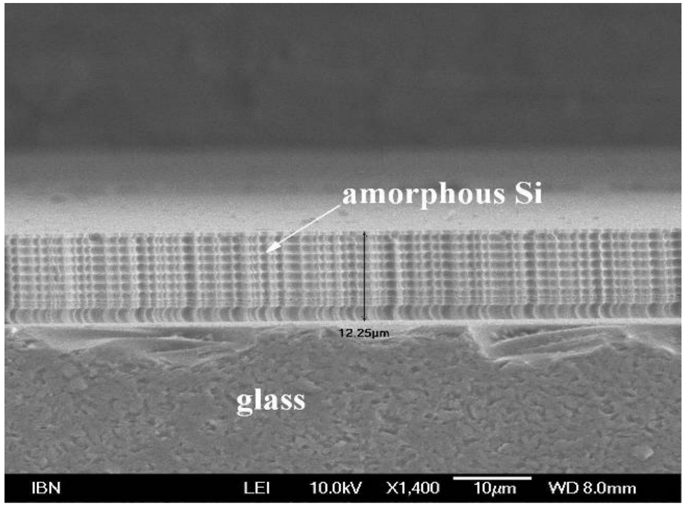
-Residual stress- is the main factor in achieving thick deposition layers of a:Si

-Deposition at low temperature (200C) in HF mode

-Deposition rates of ~100 nm/min

C. Iliescu and B.T. Chen, 2008

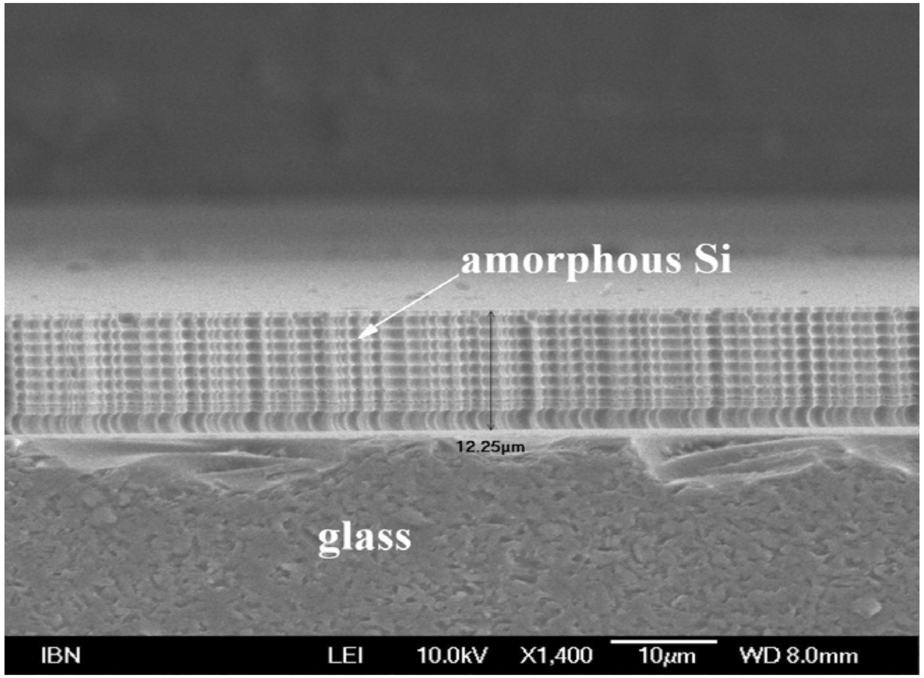
J. Micromech. Microeng. 18/1 15024(1-8)



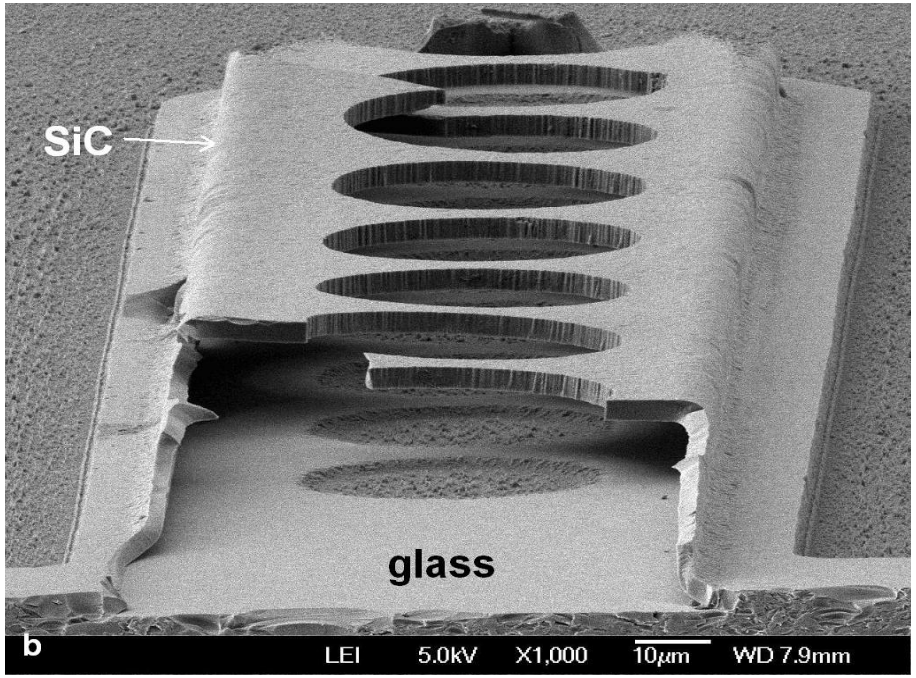
SEM image of a 12 μm thick low-stress α-Si:H film deposited on glass and patterned using a photoresist mask in a Bosch process.

MEMS and BioMEMS Applications

Applications – sacrificial layer



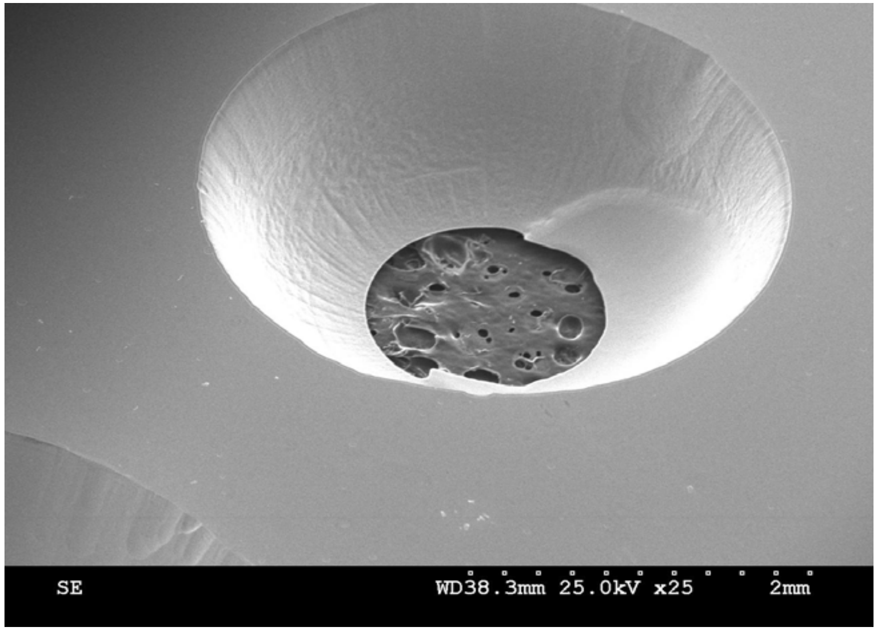
Cross section view of the 12 □m □-Si:H film on glass substrate

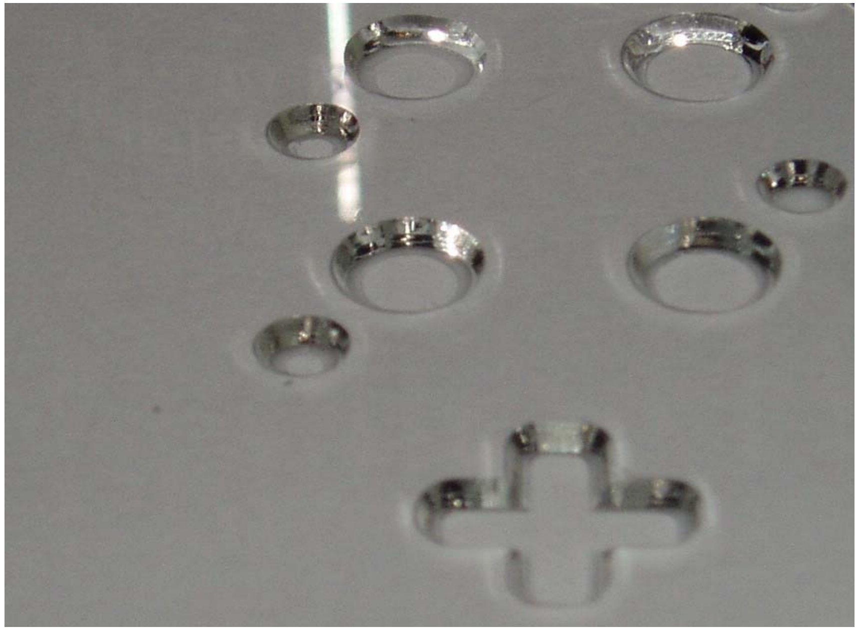


SEM image of the suspended SiC structure after release through dry etching of □-Si:H in XeF_2

Applications – masking layer in glass etching

a-Si:H layer with low stress is very good for deep wet etching of glass, without pinholes and notch defects

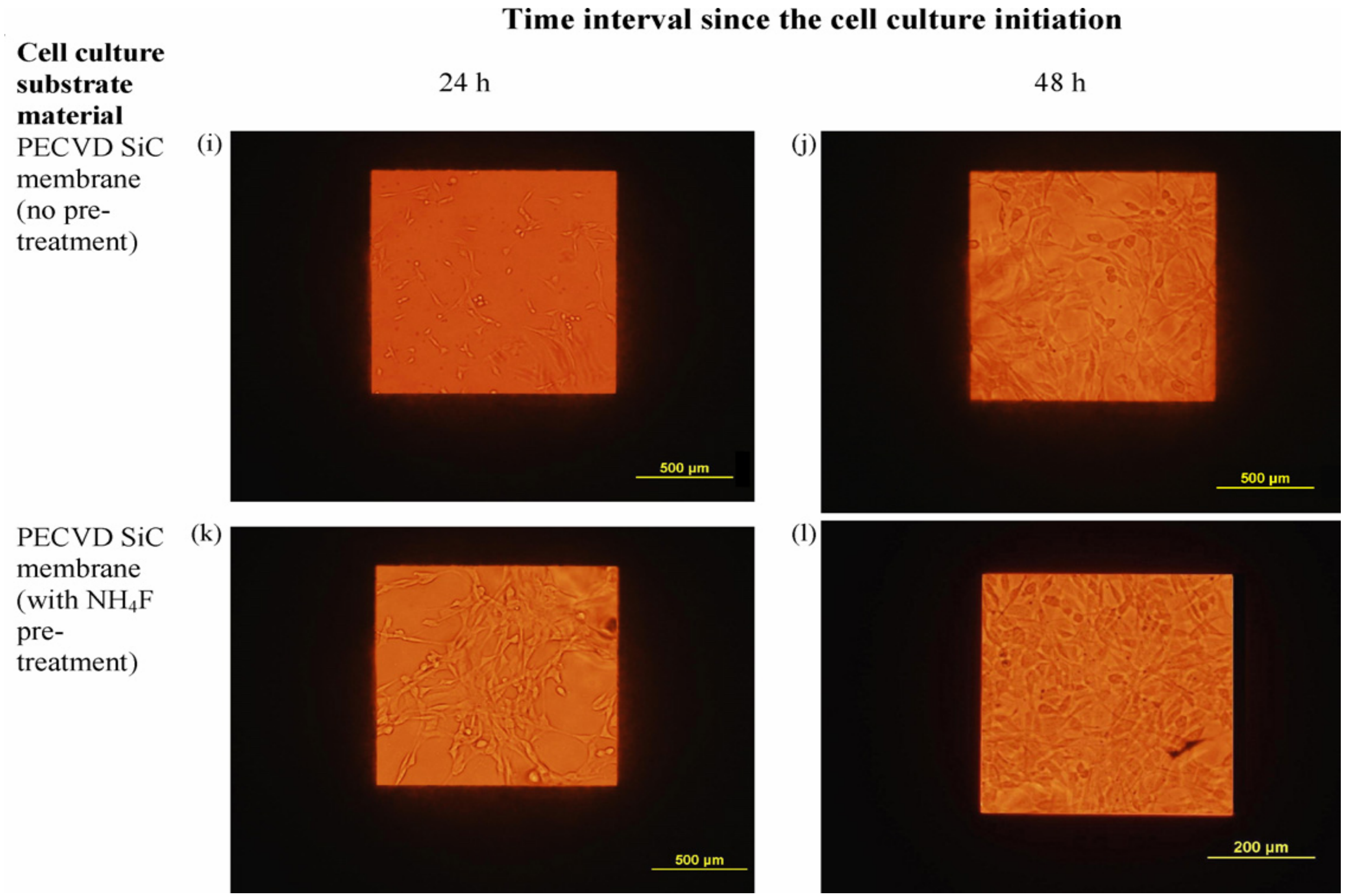




Via-holes in glass after removal of a-Si:H mask

a-Si:H layer with low stress (below -20 MPa) for via-hole glass etching

PECVD SiC membrane for cell culturing



C. Iliescu, B.T. Chen, D.P. Poenar and Y.Y. Lee, *Sensors and Actuators B* **vol. 129, issue 1**, January 2008, pp. 404-411

Thank you!