Reactive Ion Etching of GEM foils

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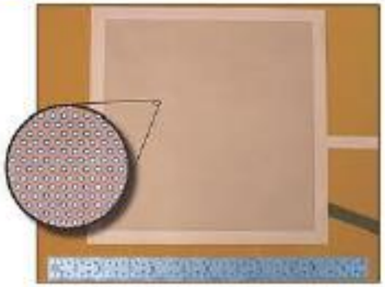
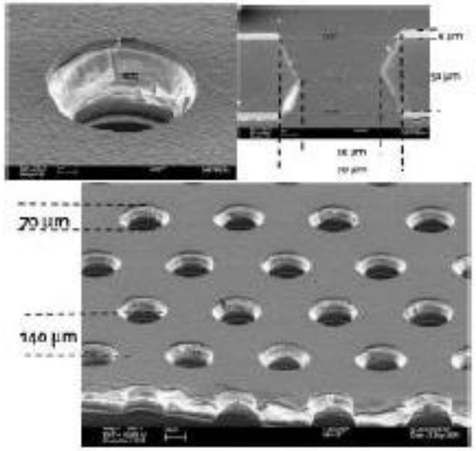
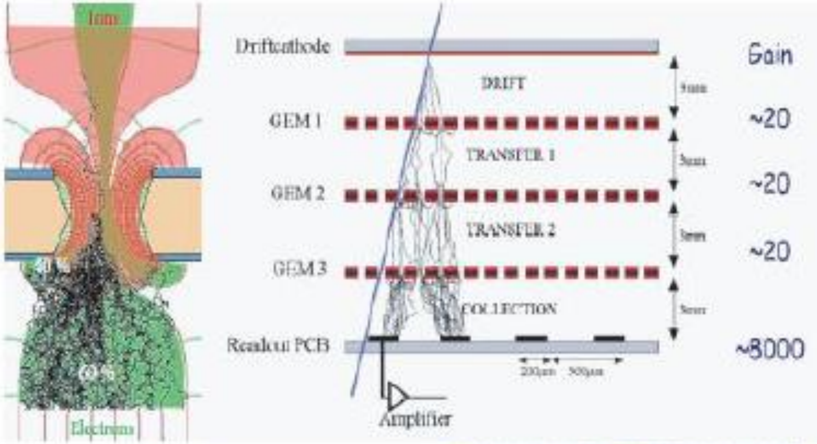
The Triple GEM for the CMS Muon System

Rate capability : 10^5 Hz/cm^2
Spatial/Time resolution: ~ 100 µm / ~ 4-5 ns
Efficiency > 98%
Gas Mixture: Ar-CO_2-CF_4 (non flammable mixture)

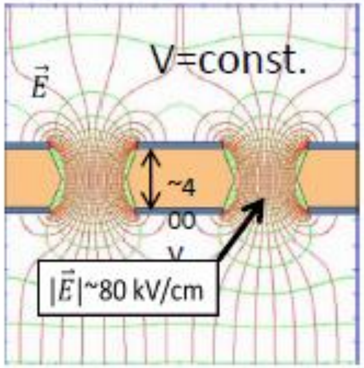
- Combine triggering and tracking functions
- Enhance and optimize the readout (η-φ) granularity by improved rate capability







- GEM foils developed using PCB manufacturing techniques
- Large areas ~ 1m x 2m with industrial processes (cost eff.)
- Each foil (perforated with holes) is 50µm kapton sheet with copper coated sides (5µm)
- Typical hole dimensions : Diameter = 70µm, Pitch = 140µm,
- Long term (10 years) operation experience in Compass, and more recently LHCb and TOTEM



Present GEM fabrication process

- Present process of GEM foils making involves Photolithography and Chemical / Electrochemical etching of copper and polyamide layers

- Uniformity and reproducibility of etching are governed by :

Rate of a chemical reaction **_:_** function of ratio of activities (Concentration) of reactants to products

Transport factor **_:_** ratio of partial pressure of a reactant reaching the surface through boundary layer to the partial pressure of reactant in gas mix

Activity at reaction surface **_:_** function of diffusivity of Reactant Species (inward) and Products Species (outward) through the boundary layer

Flow of reactants & products : across boundary layer is controlled by the thickness of boundary layer.

Disadvantages of Liquid Etching

- Reactant and products are in liquid state
- Reaction rates are highly sensitive to temperature and concentration of reacting species
- Solvent is needed to activate and transport the reacting species
- Boundary layer is thick and the layer thickness is few microns
- The supply of the reacting species to the reaction surface becomes lesser as the holes become deeper
- This problem becomes very prominent when hole diameter is nearer to boundary layer thickness
- Inner surface of the etched hole has undercutting, because of isotropicity

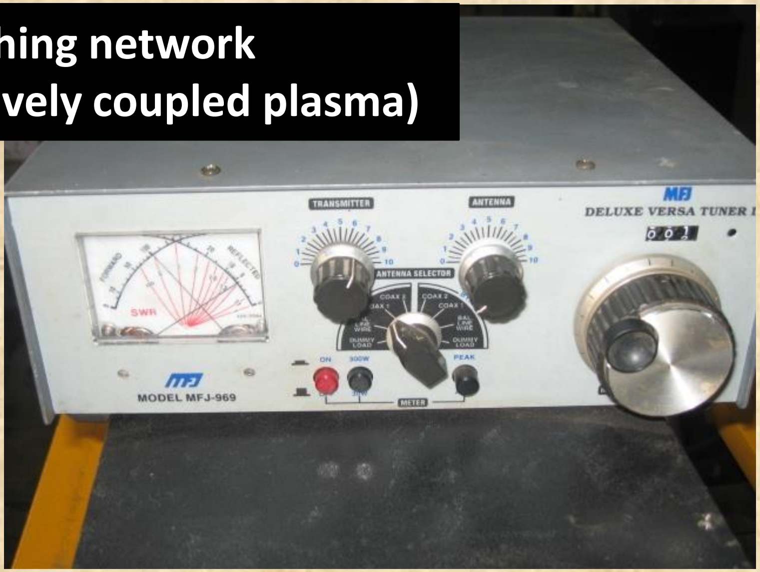
Plasma Etching : Advantages over Liquid Etching

- Gas Phase reaction - clean and precise
- **Features having Very Large aspect ratio can be etched**
- Photo-resist mask can be removed by Ashing under O_2 plasma
- Instant Change of etchants by switching gases through MFC control channels
- Galvanic protection possible to avoid over-etching of front copper layer.
- Etch process can be sequenced and programmed to etch multiple layers, in succession
- End point detection by **OES (optical emission spectroscopy)** is possible
- Surface passivation of exposed etched surface by oxygen plasma
- Excellent control over Differential etch rate between Copper and Polyimide
- DC bias : controlled ion energy for directional etching
- Very little undercutting
- **It is possible to etch copper and Kapton in – situ**

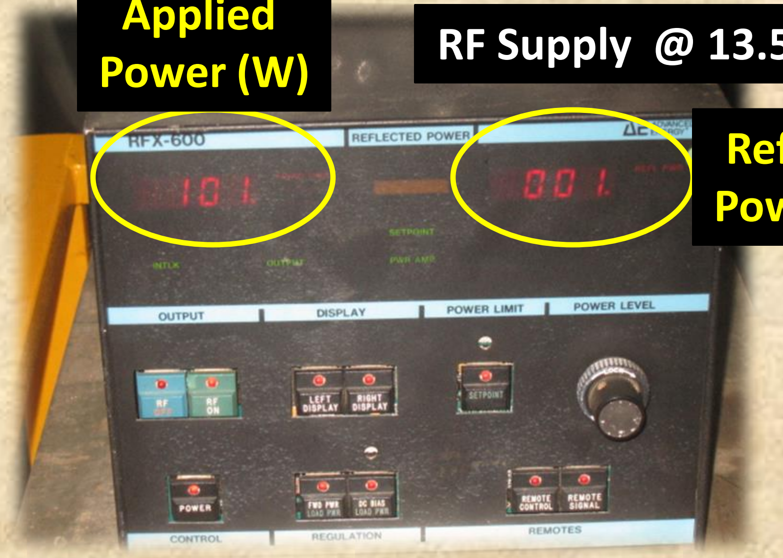
Plasma Etching : Process variables

1) RF Power density
2) Gas Mixture component types
3) Gas mixture Ratio
4) Pressure
5) Substrate Temperature
6) Electrode spacing : 19 mm with GEM foil at ground

Plasma Etching at Alpha Pneumatics, Thane Factory



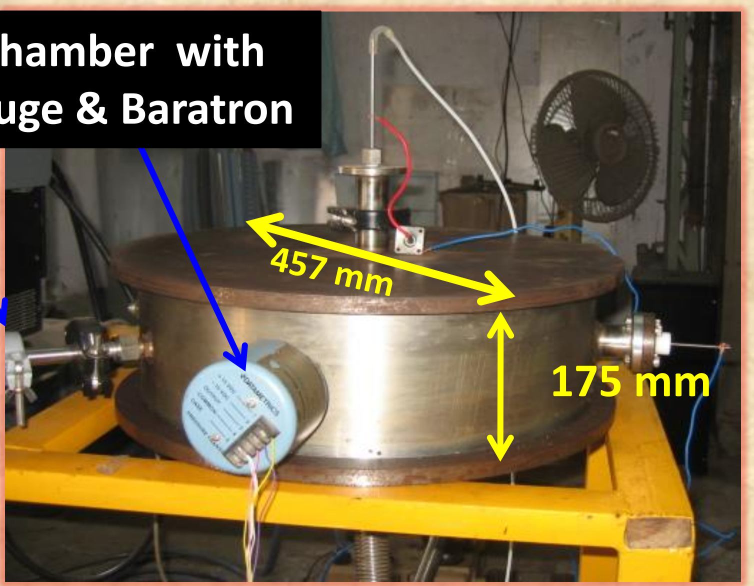
RF matching network
(capacitively coupled plasma)



Applied Power (W)

RF Supply @ 13.56 MHz

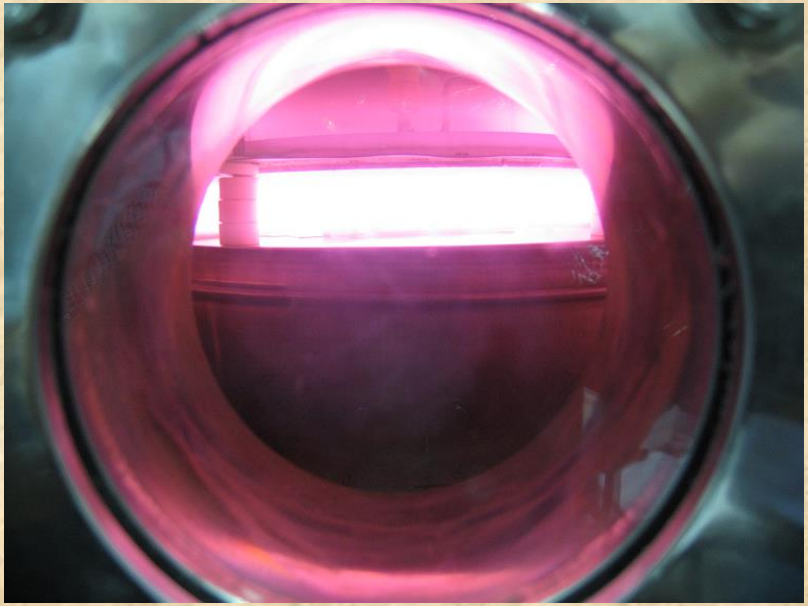
Reflected Power (W)



Process Chamber with
Pirani Gauge & Baratron

Tuning the plasma

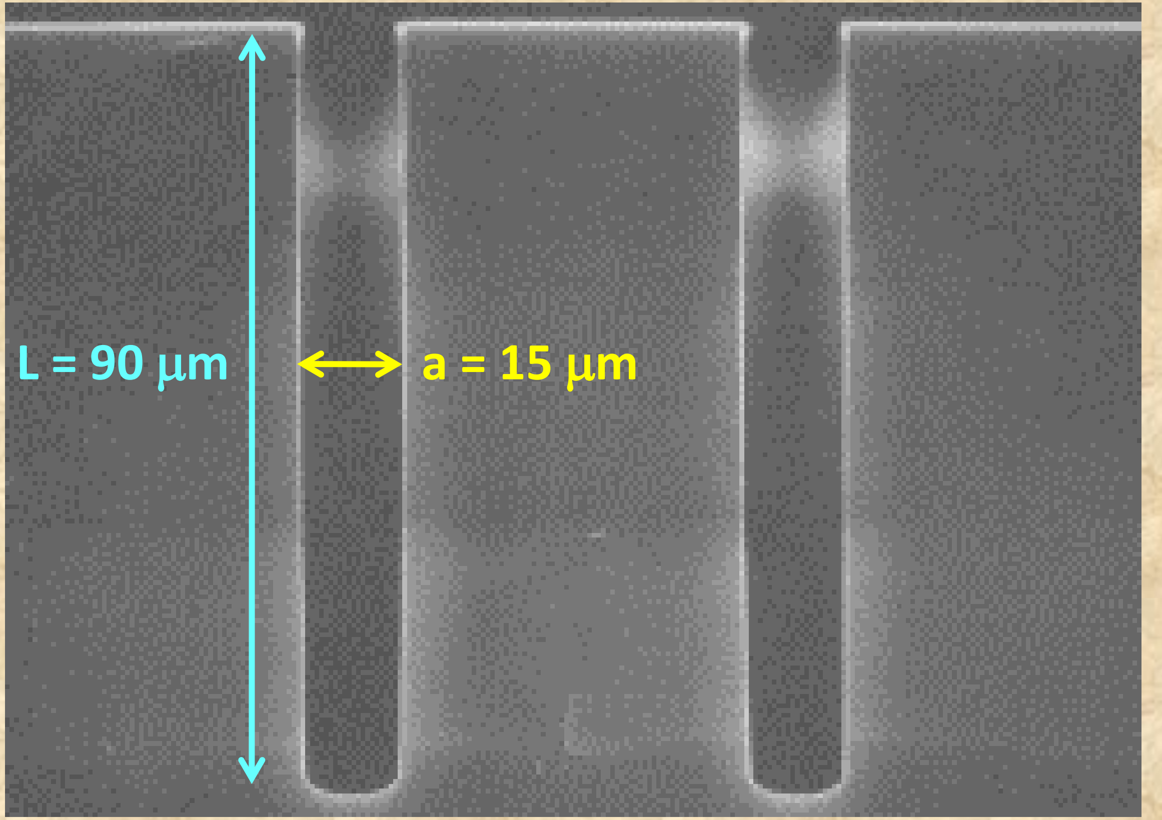
RF Plasma at 0.4 to 1.0 Torr : 19 mm electrode spacing



with O_2 (100%)

with SF_6 (100%)

SEM photograph of plasma etched silicon grooves with large aspect ratio (L/a)



Etch rate of polymide versus SF_6 concentration in O_2

Ref : "Dry Etching of Polyimide in O_2-CF_4 and O_2-SF_6 Plasmas" Guy Turban and Michel Rapeoux , Journal of Electrochem. Soc. Solid State Science and Technology, p 2231-2236, Nov. 1983

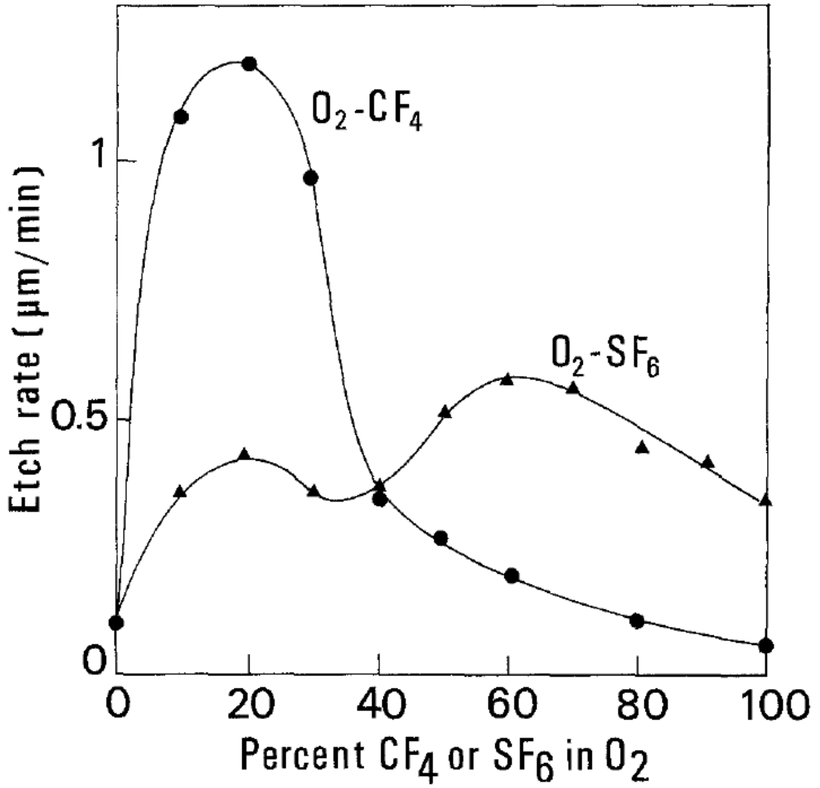


Fig. 3. Etch rates of Kapton in O_2-CF_4 and O_2-SF_6 discharges. Pressure = 0.2 Torr, sample area = 4.5 cm^2, frequency = 13.56 MHz.

Etch rate of polymide versus SF_6 concentration in O_2

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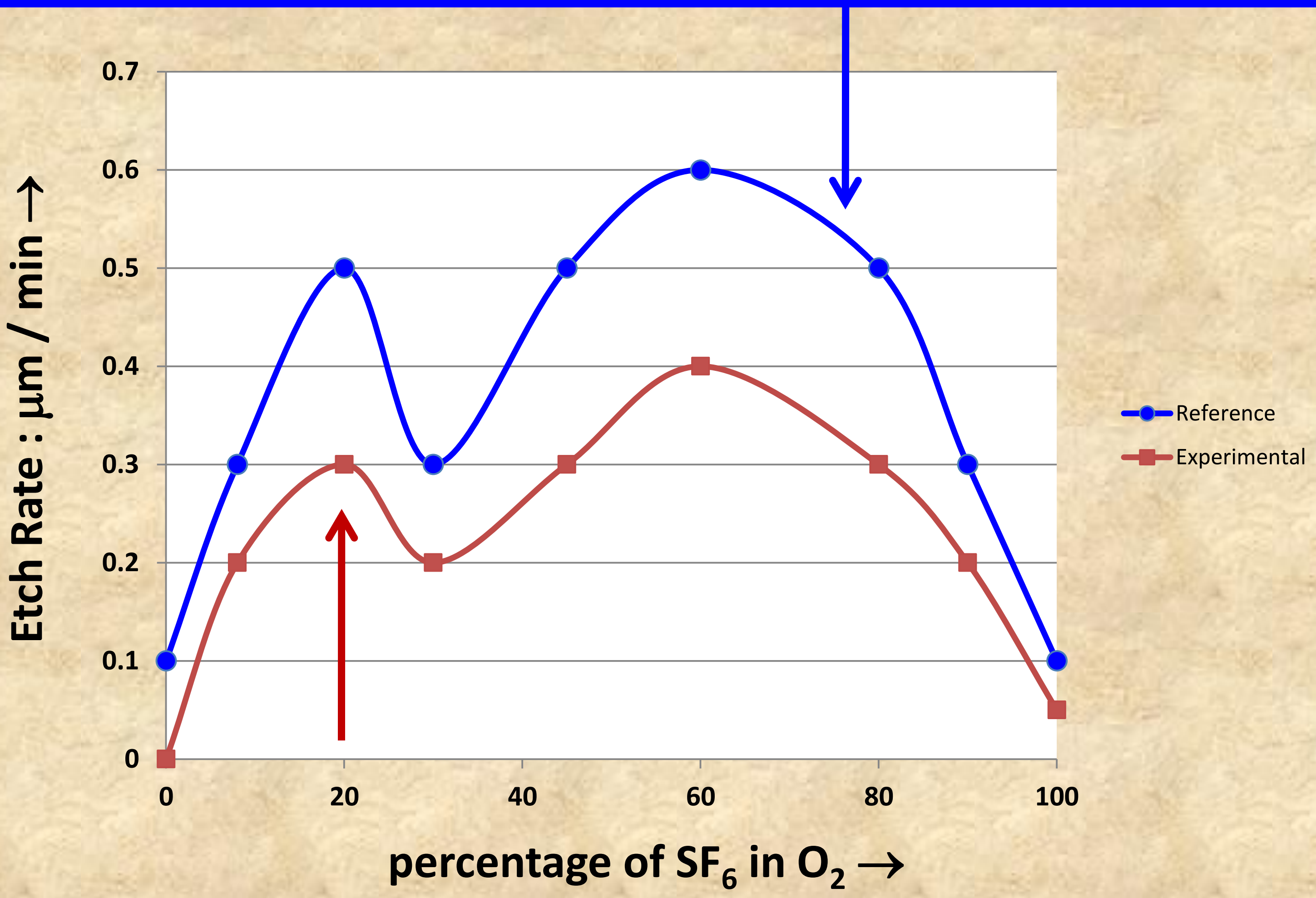
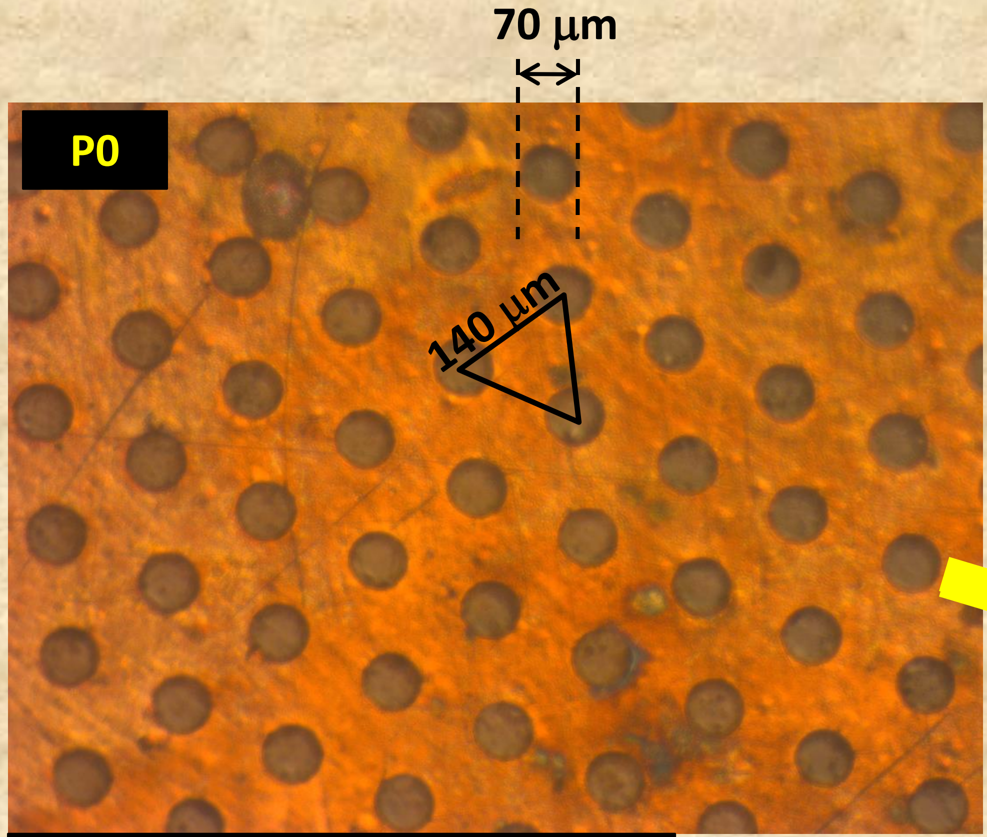


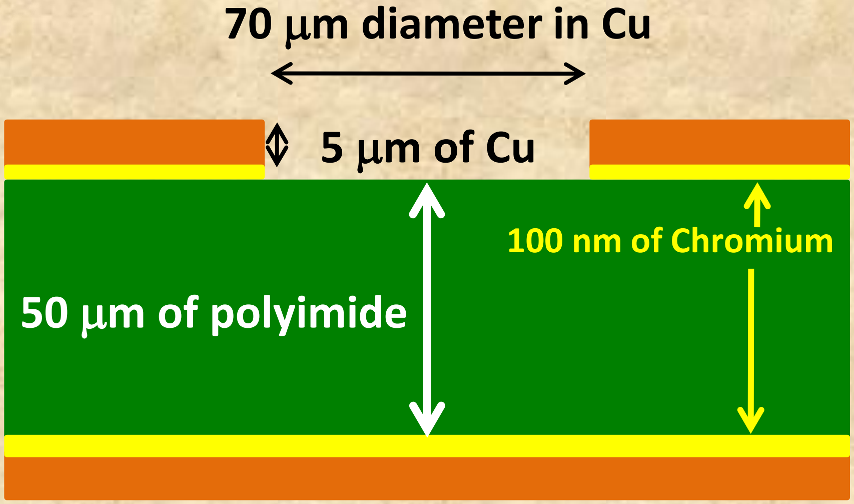
Etching Parameters

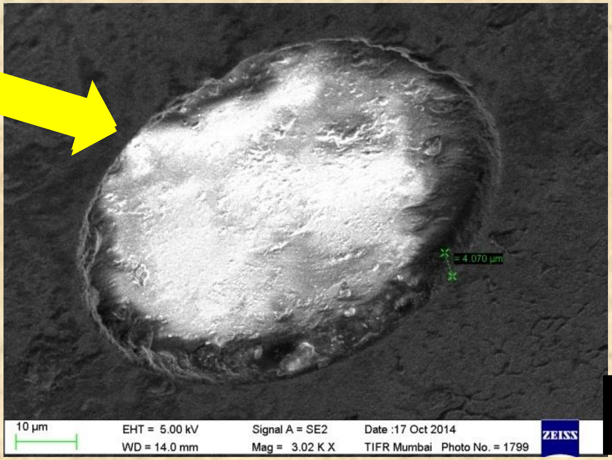
- **Gas Pressure : 0.6 torr**
- For Polyimide (Kapton)
  - a) SF_6 : 6.0 SCCM (20%)
  - b) O_2 : 24.0 SCCM (80%)
  - c) RF Power Density : 0.6 to 1.2 W/cm^2
  - → **d) Maximum Etch Rate Achieved : 0.3 μm/min**
- For Copper
  - a) SF_6 : 24.0 SCCM (80%)
  - b) O_2 : 6.0 SCCM (20%)
  - c) RF Power Density : 0.6 to 2.0 W/cm^2
  - → **d) Maximum Etch Rate Achieved : 0.05 μm/min**
  - e) Substrate Temp : $25^{O}C$/Start, $35^{O}C$/End
  - f) Duration : 10.0 min

Rejected Polyimide foil from CERN with Cu already patterned at 70 μm diameter



Courtesy : Shuvendu, ASD-BARC





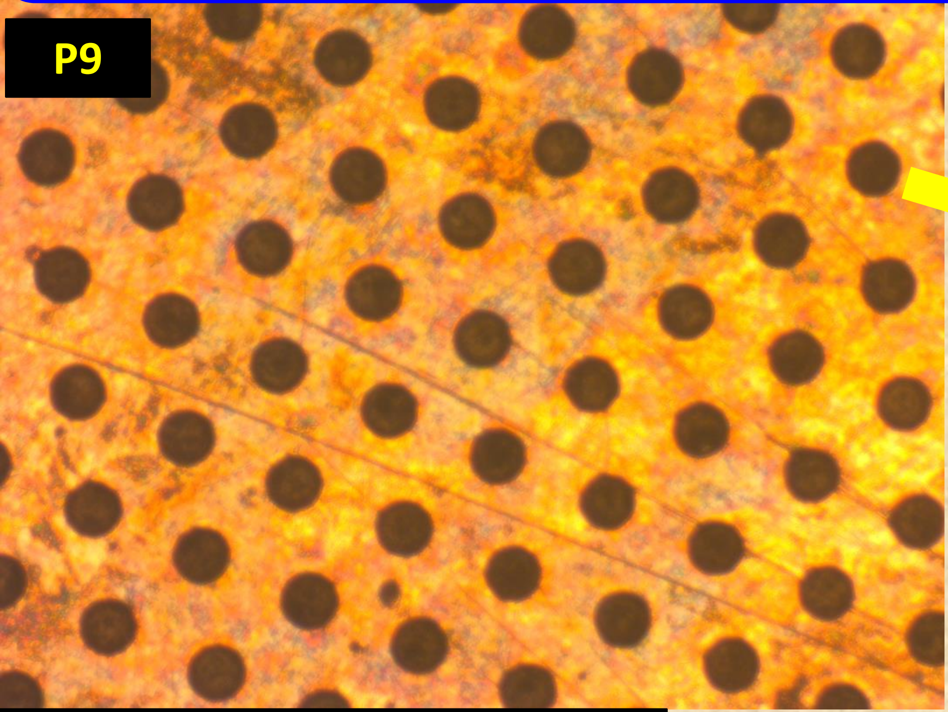
SEM view

~ 18 µm deep trench in Polyimide in 48 minutes under SF_6 (20%) + O_2 plasma

SEM view

~ 24 μm deep trench in Polyimide in 60 minutes under SF_6 (20%) + O_2

Note , there is no undercutting



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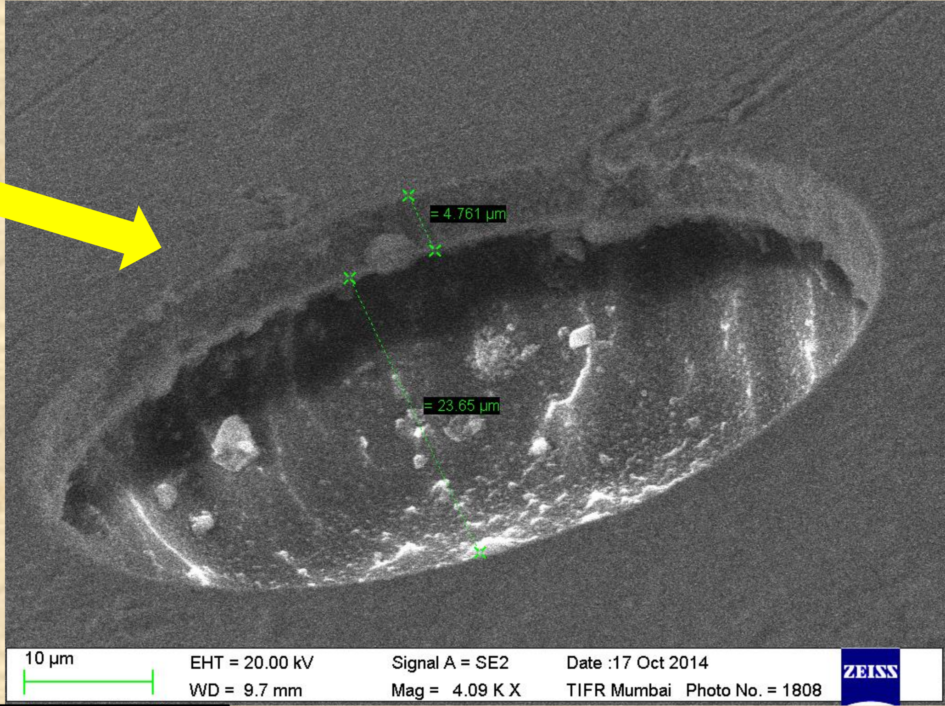
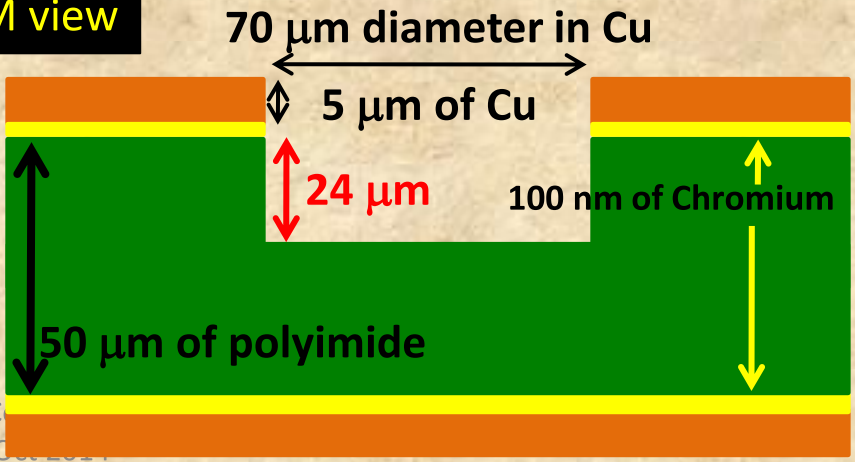
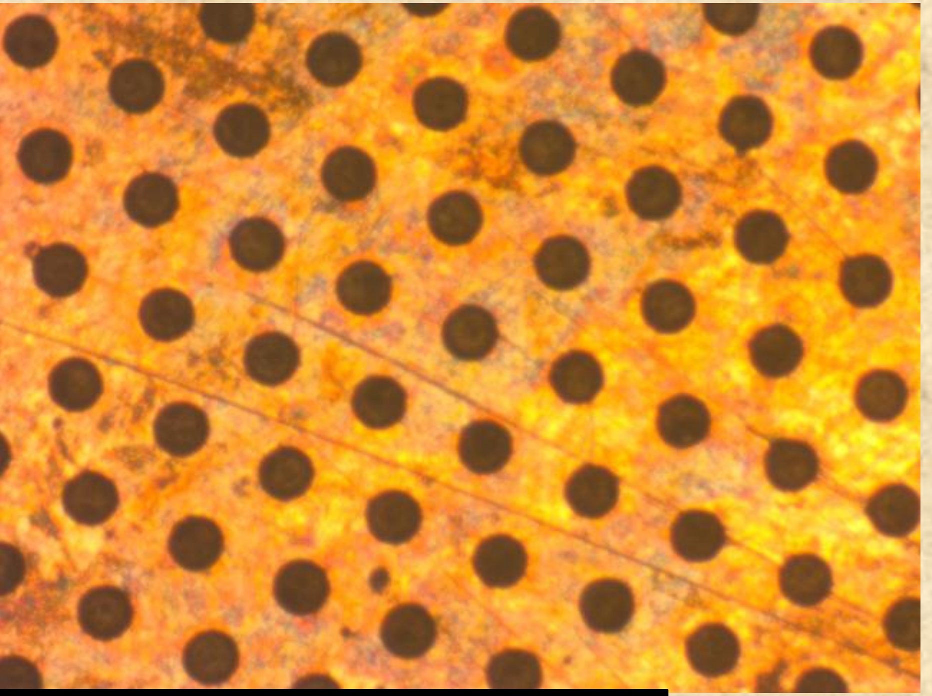


SEM view



~ 30 µm deep trench in Polyimide in 60 minutes under SF_6 (20%) + O_2 plasma



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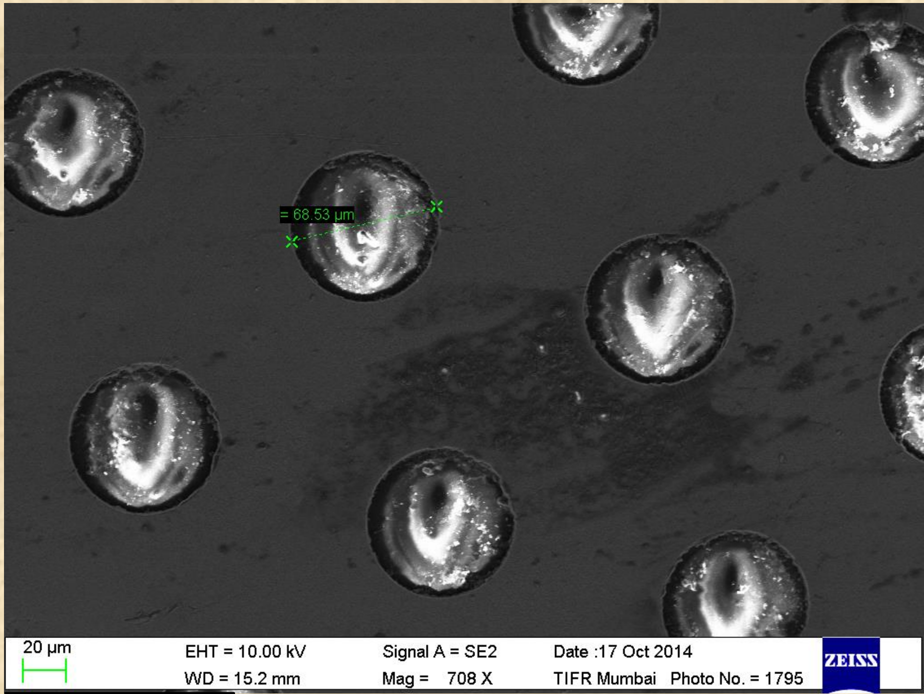
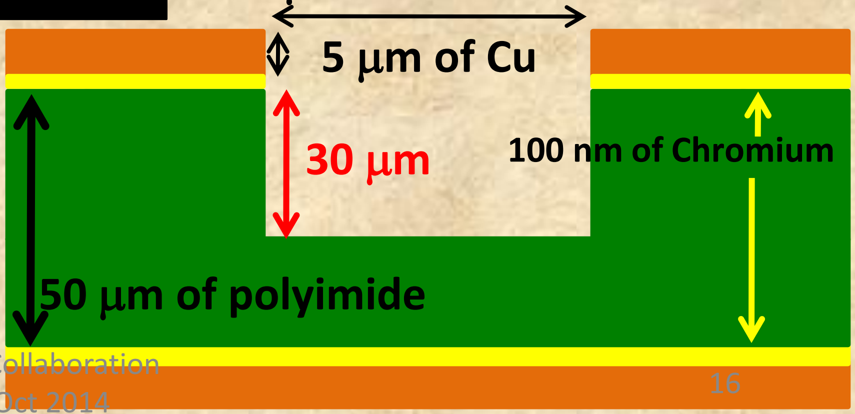


SEM view



70 µm diameter in Cu

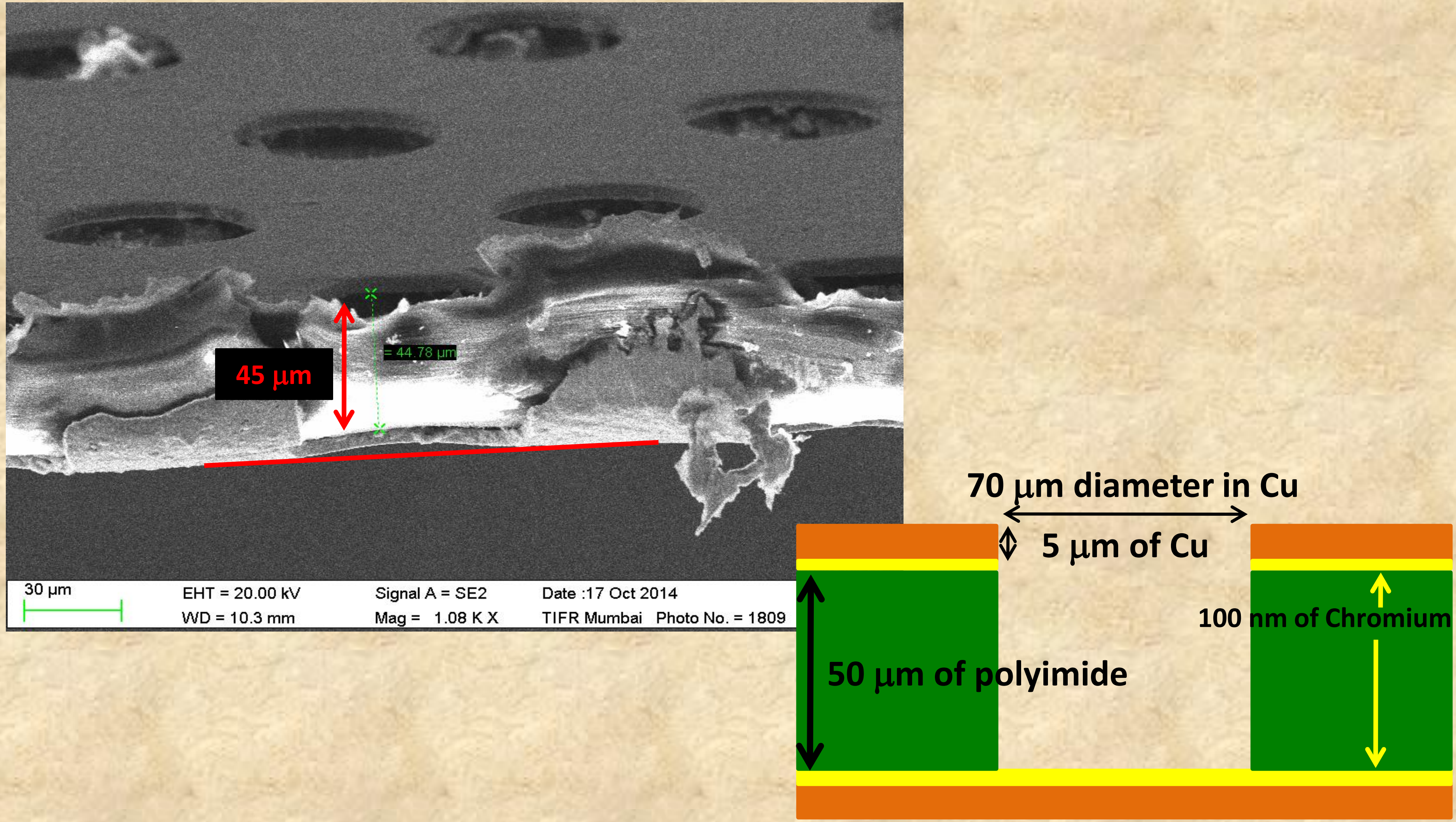
5 µm of Cu

30 µm

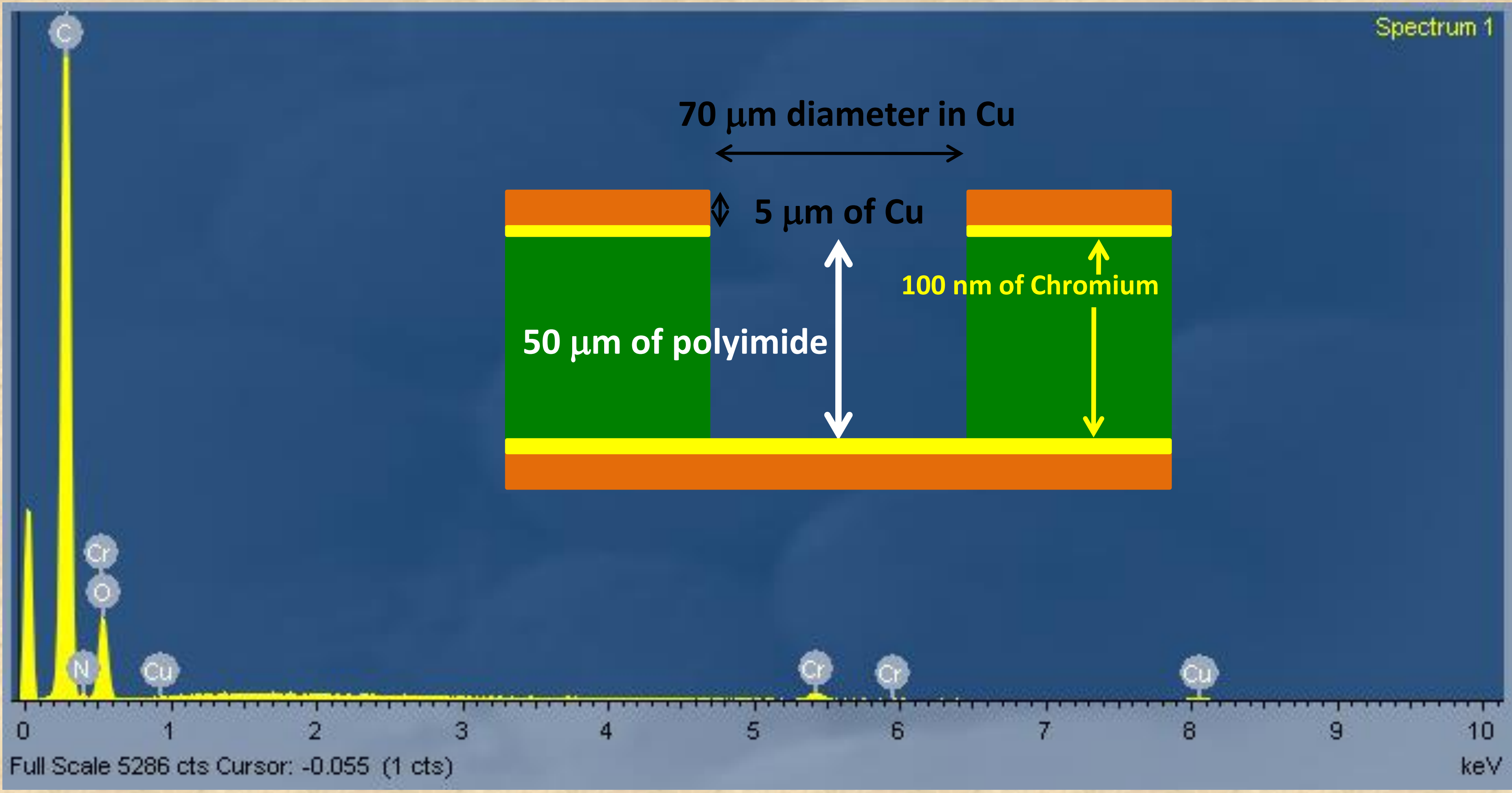
100 nm of Chromium

50 µm of polyimide

Polyimide etched to a depth of 50 μm in 120 minutes under SF_6 (20%) + O_2 plasma

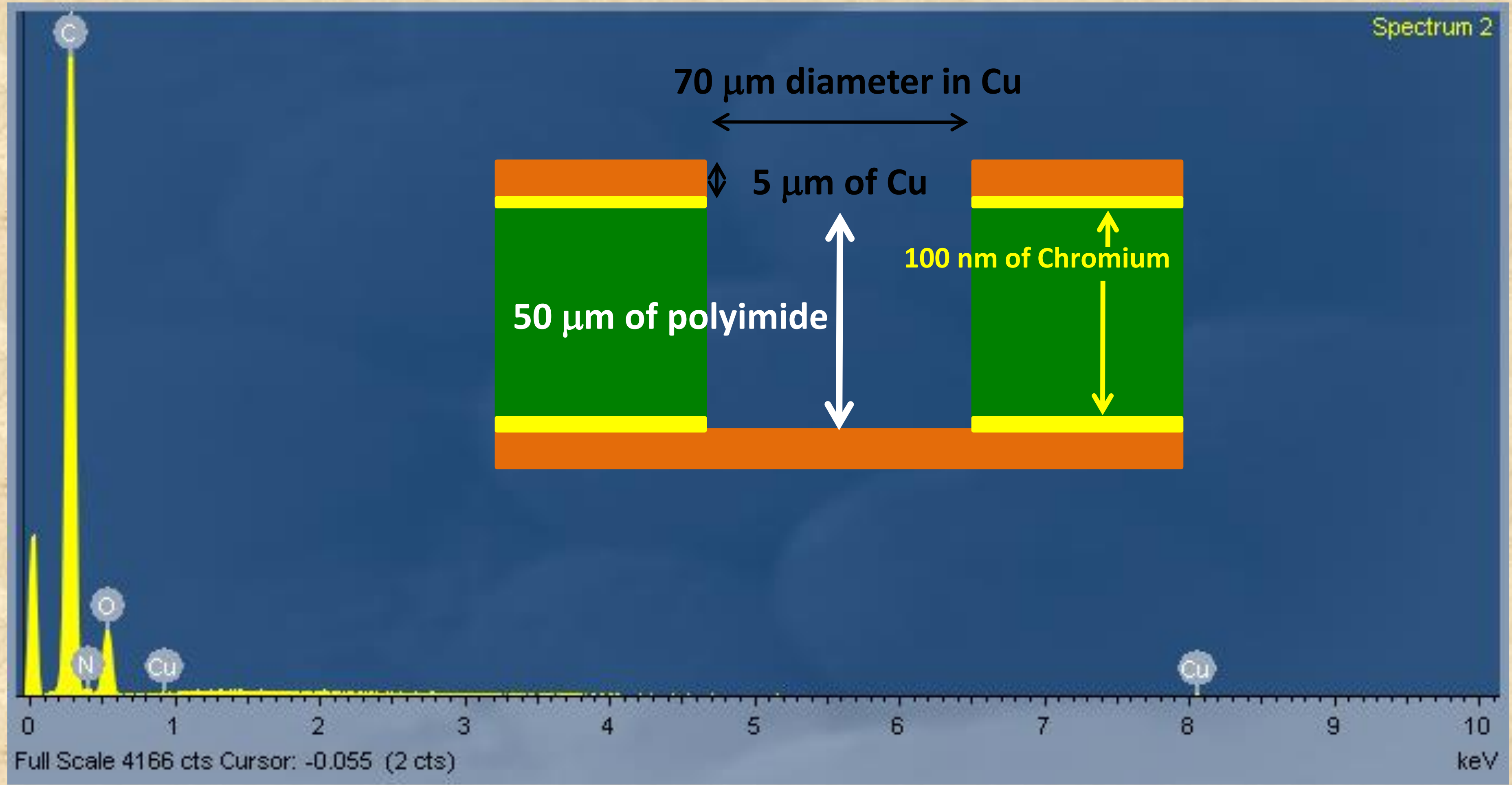


EDAX measurement of surface chemistry showing presence of Cu and Cr in the bottom layer



EDAX measurement of surface chemistry showing absence of Cr in the bottom layer

reverse concentration : SF_6 (80%) + O_2 (20%) flash for a couple of minutes



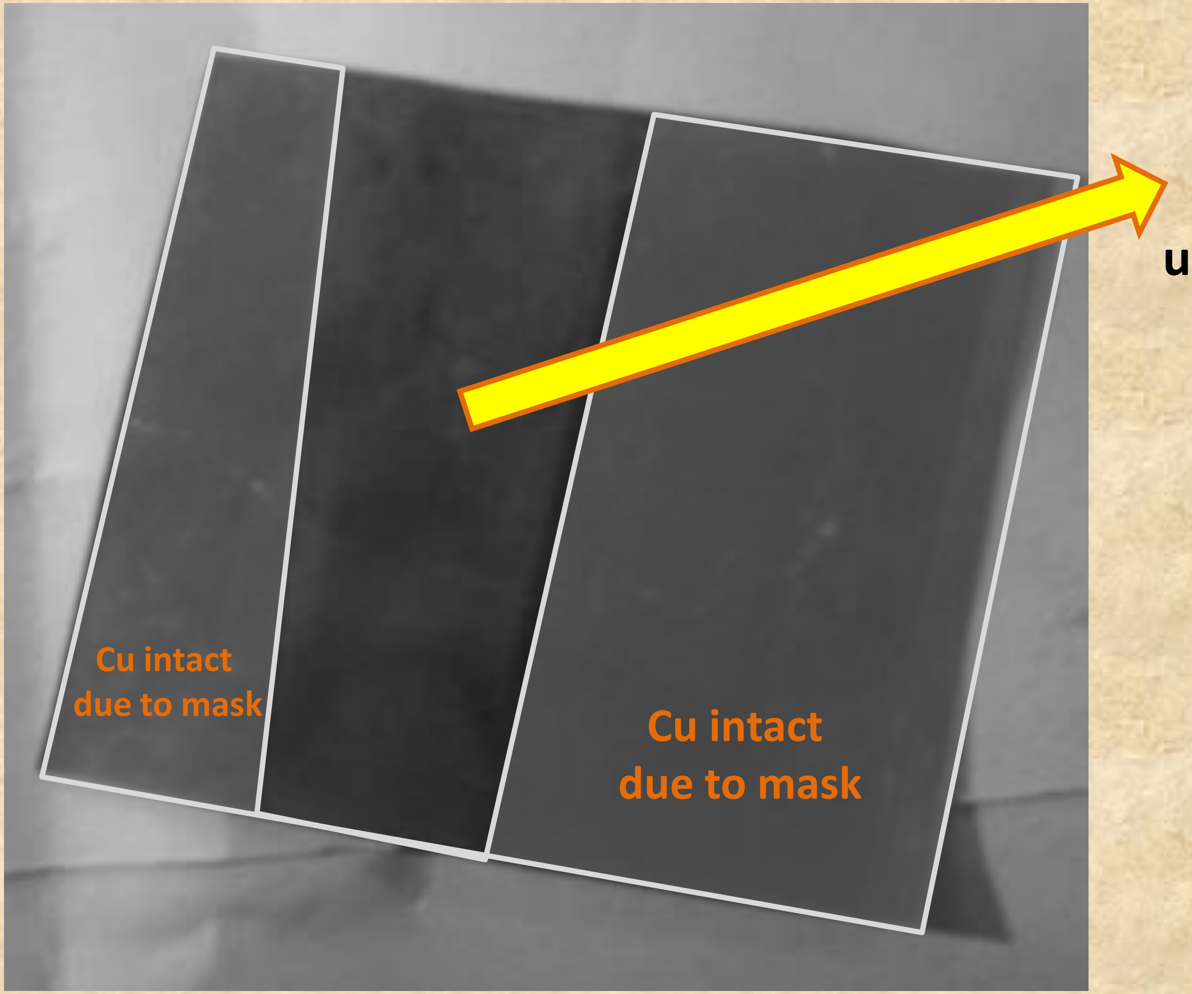
70 μm diameter in Cu

5 μm of Cu

100 nm of Chromium

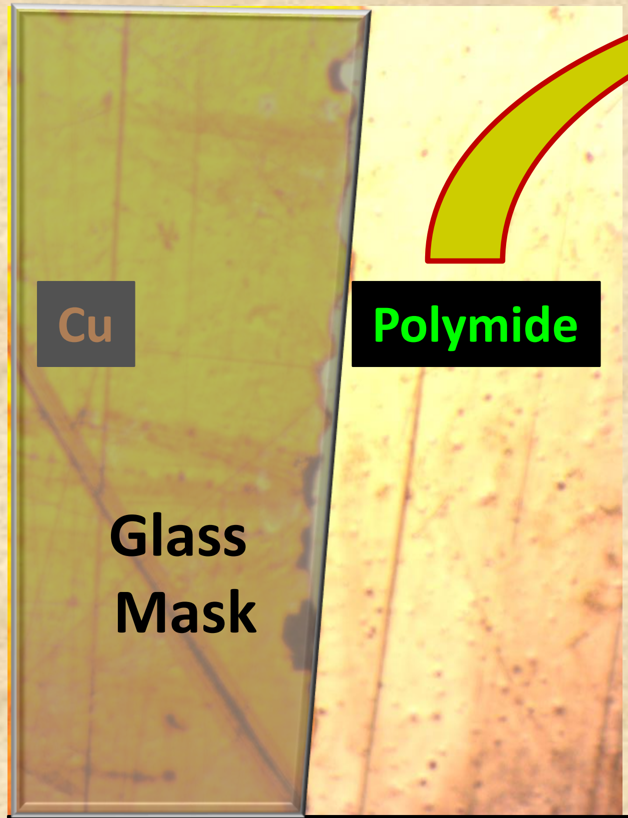
50 μm of polyimide

Etching of Copper on Polyimide
SF_6 (90%) + O_2



0.2 μm of Cu etched from unmasked surface

5 µm etching of Copper on Polyimide (5000 X)
SF_6 (90%) + O_2



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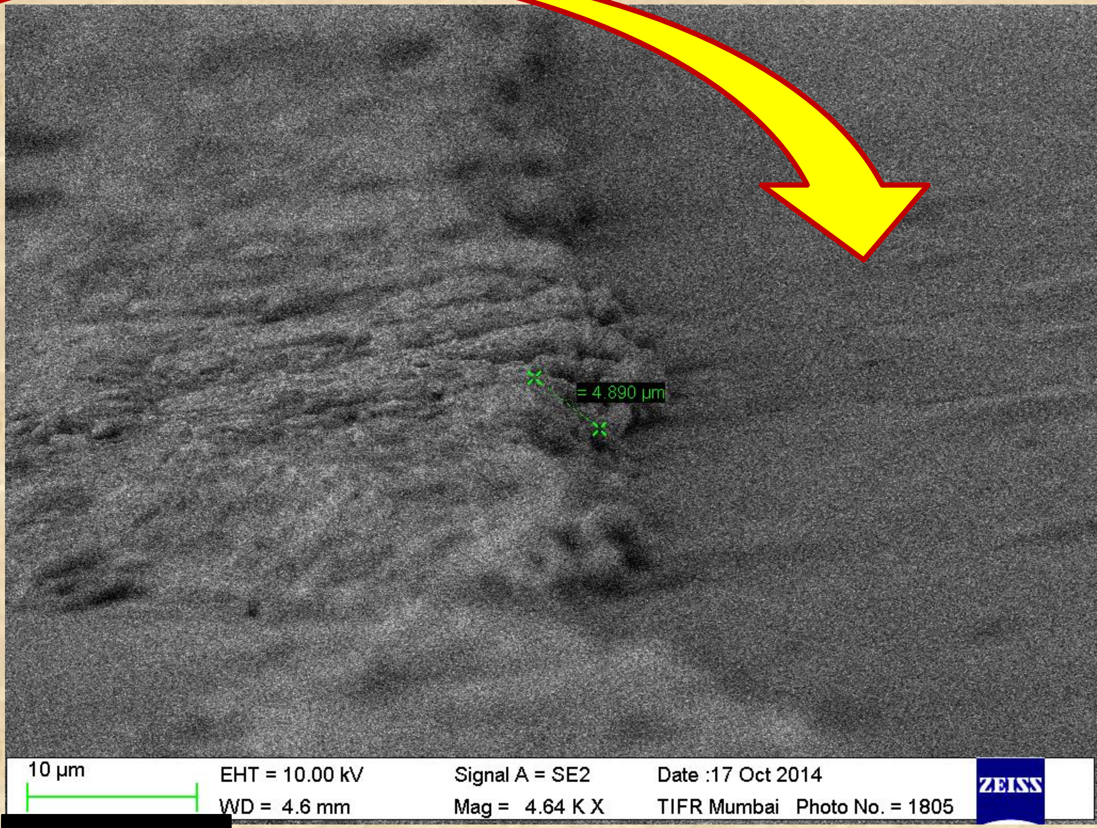


SEM view

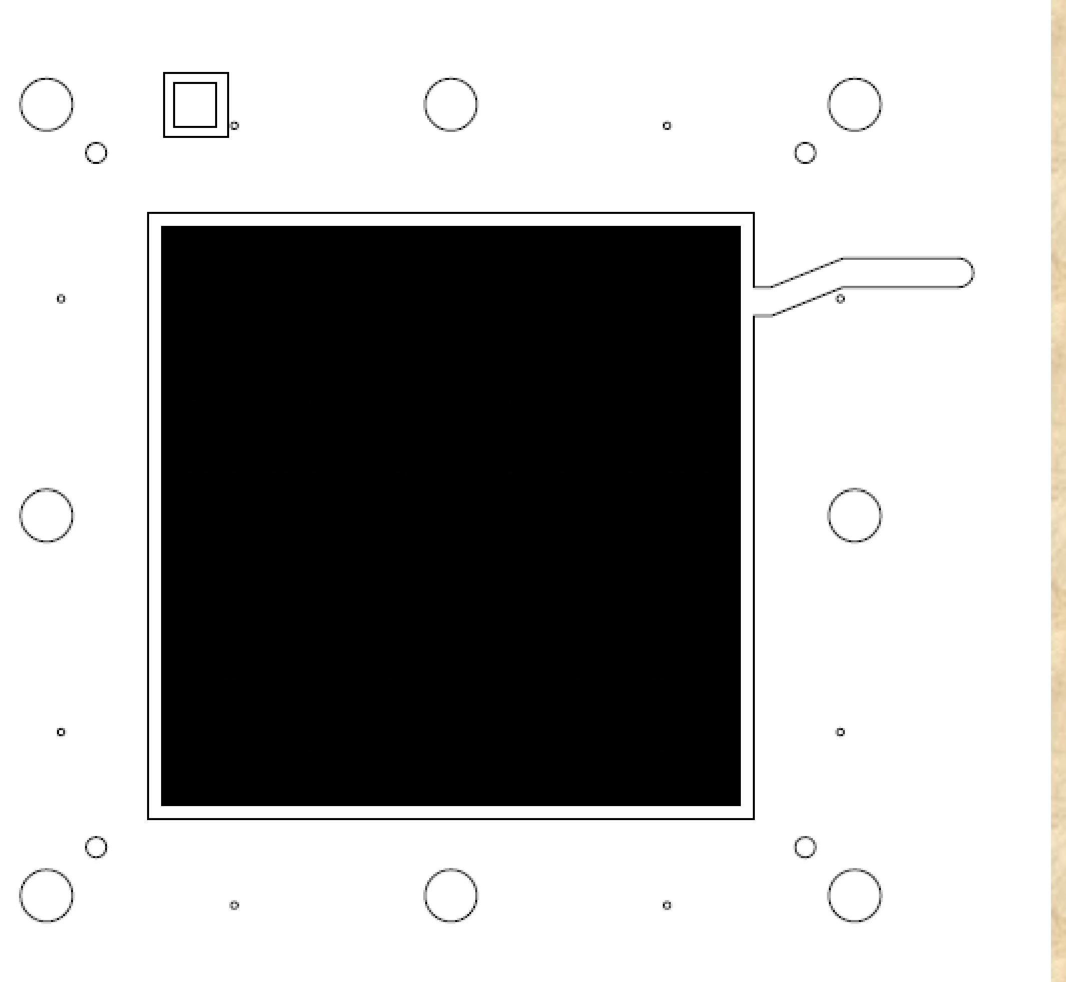
Cl_2 as an alternative to SF_6

1) Cl_2 gives better results than SF_6

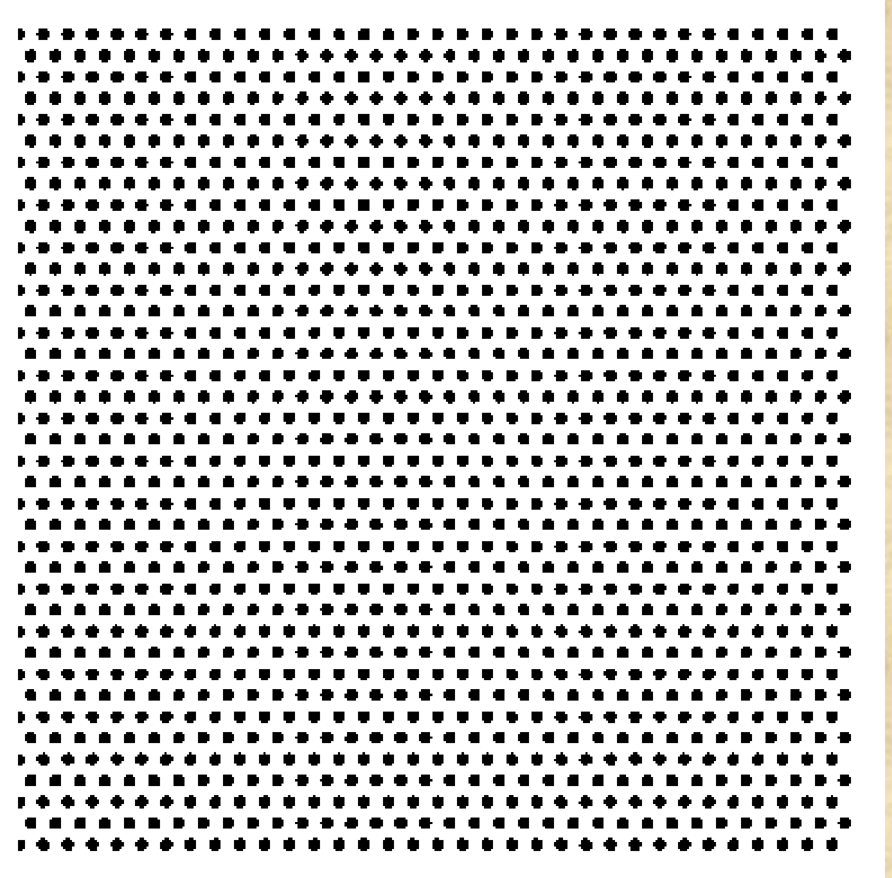
2) With $SF_6 + O_2$ mixture, higher surface temperature (214^OC) is required to evaporate the products

3) Etch rates of 0.5 μm/min (x10)have been achieved under $Cl_2 + O_2$ plasma and UV irradiation

Artwork and Mask making : Image of GEM foil mask



Artwork and Mask making : 1/100th part of artwork



- Drawing prepared in Auto Cad 2004 platform
- Front and Back side contact /proximity masks
- Total 591000 elements per mask
- Single reticule of 185 mm x 175 mm size

Present Status :

1) Artwork prepared by us, which has been okayed by CERN

2) We are in touch with emulsion mask makers from US and commercial negotiations are going on to prepare emulsion and chrome type contact masks.

Summary and Outlook

- **An etch rate of 0.5 μm/min for Polymide and 0.05 μm/min for Cu has been demonstrated**
- Possible modifications / Etchants for future RIE processes for GEM
- Gases : SF_6, CF_4 , O2 ,CH_2FCF_3 (R134a) , Cl_2, Argon and Nitrogen, Organometallics
- SF_6 and CF_4 more suitable than R134a as Fluorine yield is significantly higher
- **Cl_2 and O_2 plasma etch copper but does not affect Polymide**
- **SF_6 and O_2 plasma etch PMMA but does not affect copper but etch rate is very poor**
- Power density of 0.5 Watt/cm^2 is adequate
- CCP or ICP methods can be used for large area
- Process of RIE under UV radiation to facilitate CuClx evaporation
- We are using CCP technique (@13.56 MHz)

References

1) “Dry Etching of Polyamide in O2-CF4 and O2-SF6 Plasmas”
Guy Turban and Michel Rapeoux , Journal of Electrochem. Soc. Solid State Science and Technology pp2231-2236 Nov. 1983

2) “ Dry Etching of Copper Using Plasma” by Kejun Xia
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3)“Plasma etching of copper films at low temperature”
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