Secondary electron yield of nano-thick aluminum oxide and its application on MCP detector

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Outline

- Background
- Experimental
- Results and Discussion
- Application and Challenges Forward
- Conclusions and Perspectives

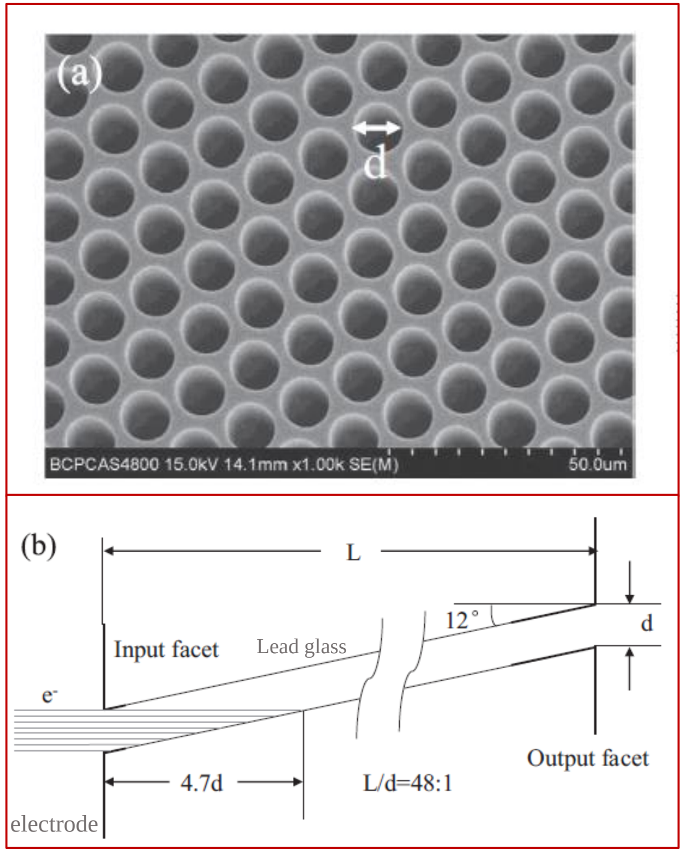
Background

How to improve the performance of microchannel plate (MCP) assembly

Make MCP assembly performance better!

- Gain (Single electron counting)
- Resolution (Energy, Temporal and spatial)
- Peak to Valley ratio (P/V)
  ....

- Length to diameter ratio (L/D)
- Large open area ratio (OAR)
- **High secondary electron yield (SEY) material**



(a) Scanning electron microscope picture of MCP; (b) a micro channel

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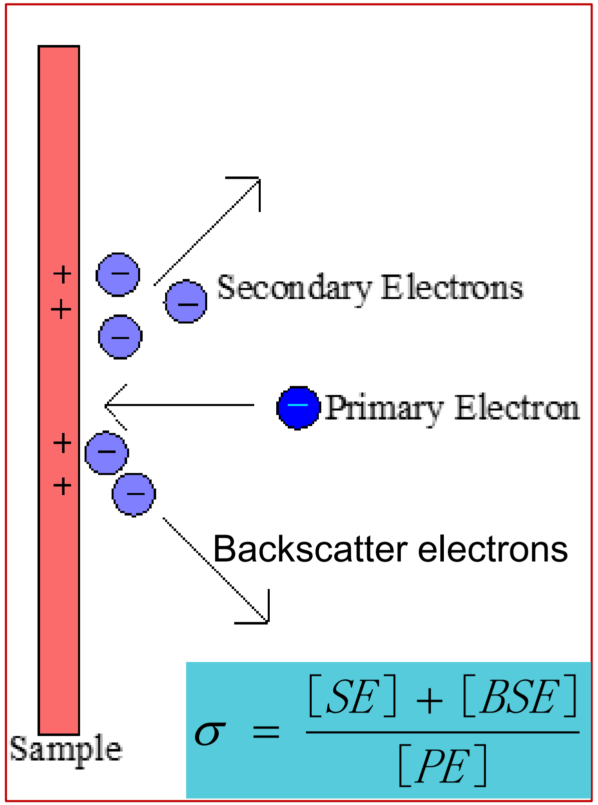
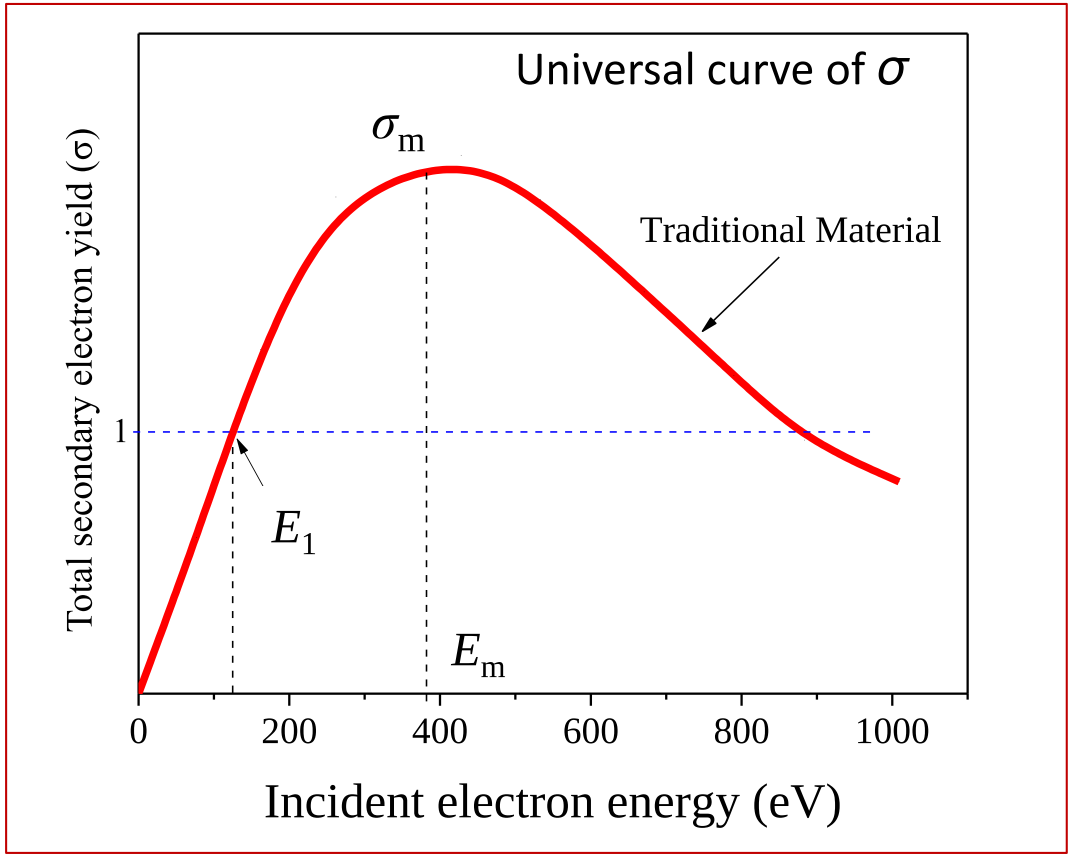
Definition



Total reflective secondary electron yield (σ)

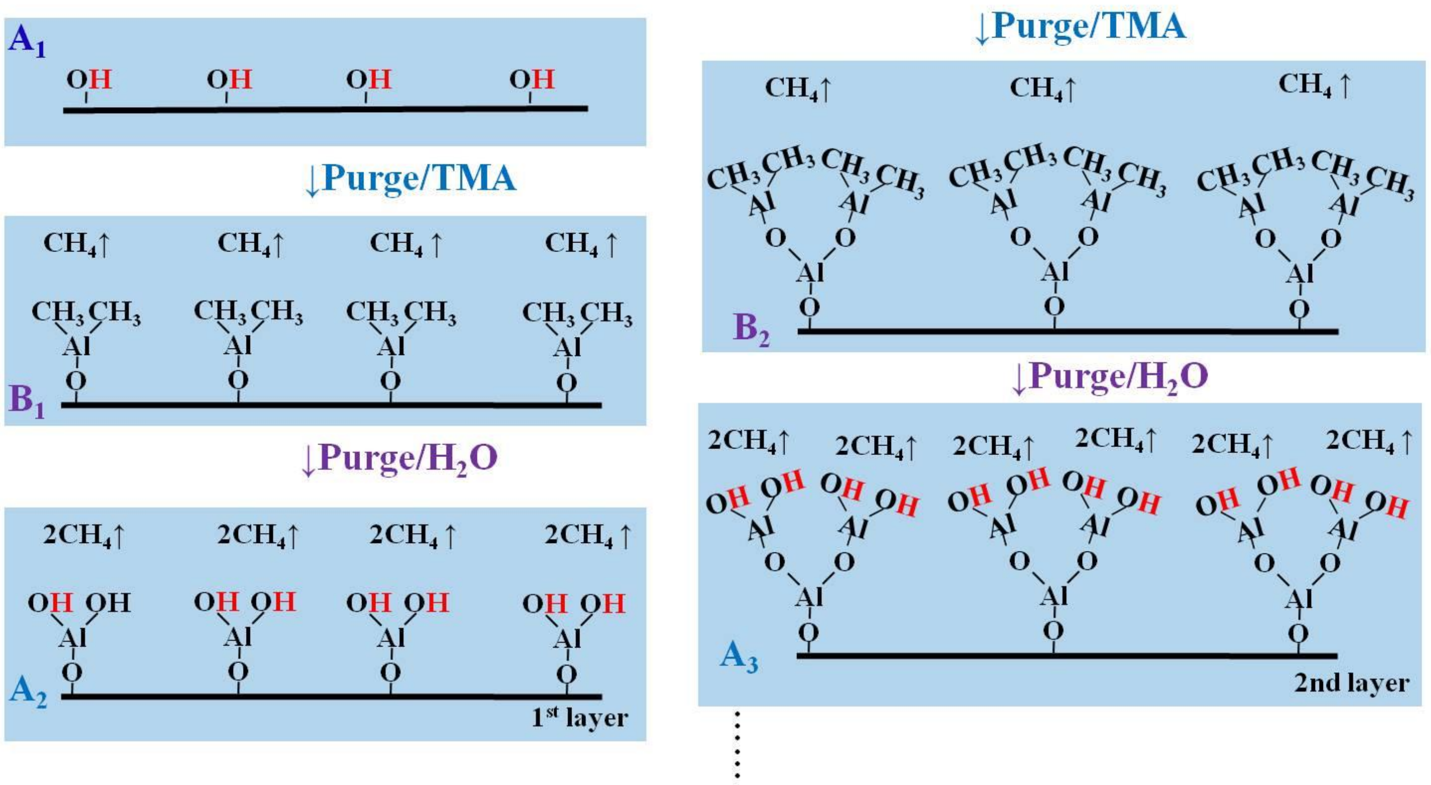


At low primary electron energy, the σ is low and gradually increase to maximum σ_m at optimum E_m, and then decreases slowly. For lead glass, σ_m is less than 2.5 at the optimum energy of 300 ~ 500 eV.

Experimental

A. Sample preparation

- Aluminum oxide deposited by atomic layer deposition (ALD) technique



Schematic illustration of ALD Al_2O_3 growth process.

- Substrate: N-type silicon
- Thickness： ~10 nm (100 AB cycles)

(by Spectroscopic Ellipsometry)

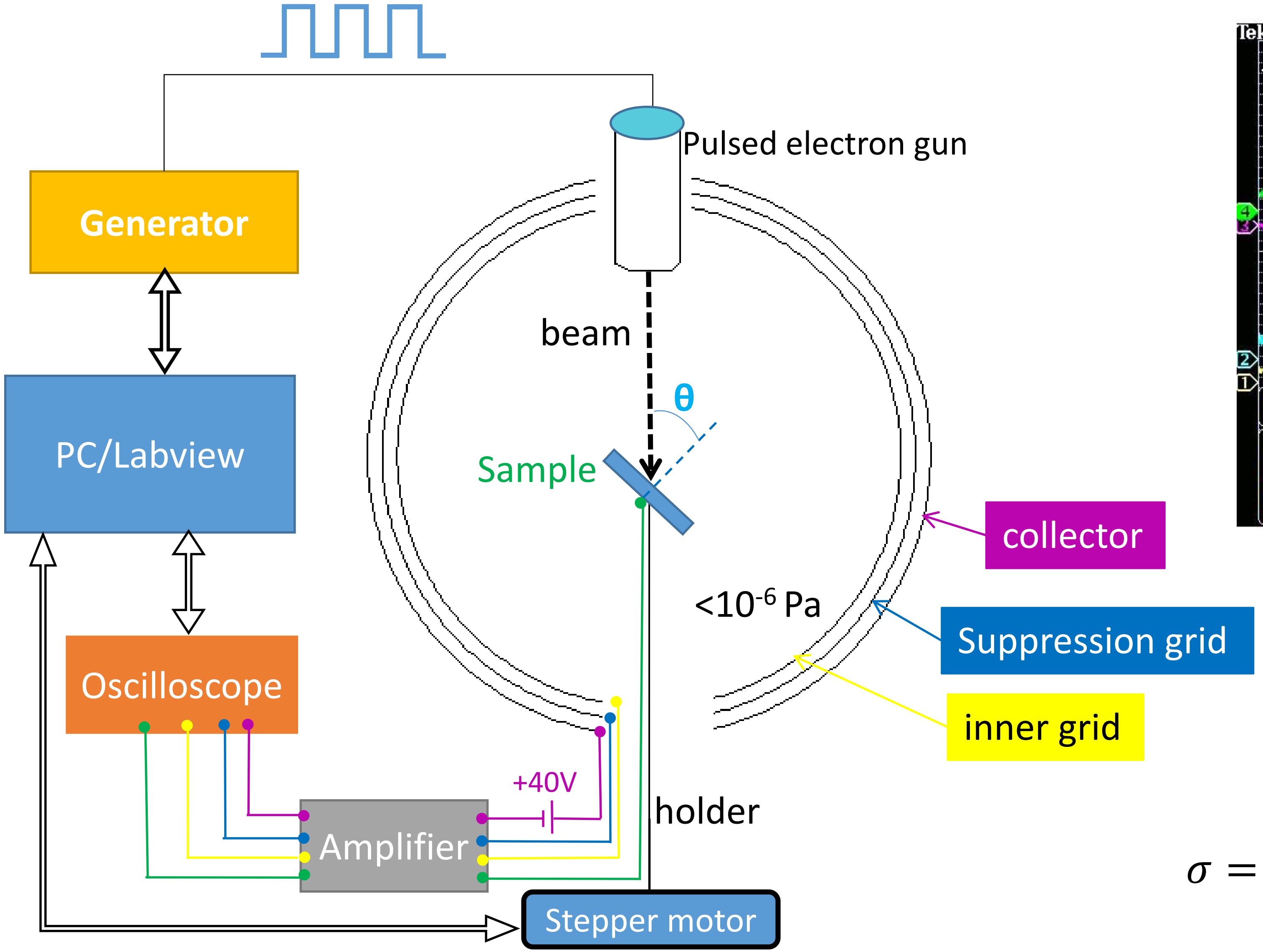
- Microstructure: amorphous

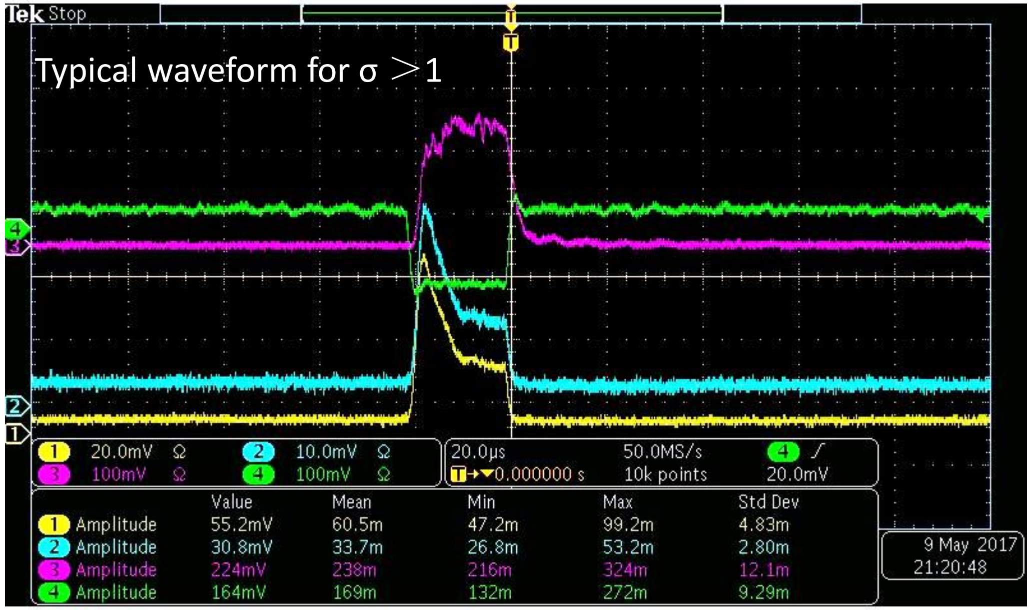
(by X-ray diffraction)

Nanoscale Research Letters (2015) 10: 162.

Applied Surface Science 371 (2016) 118–128

B. Pulsed-Yield Measurement





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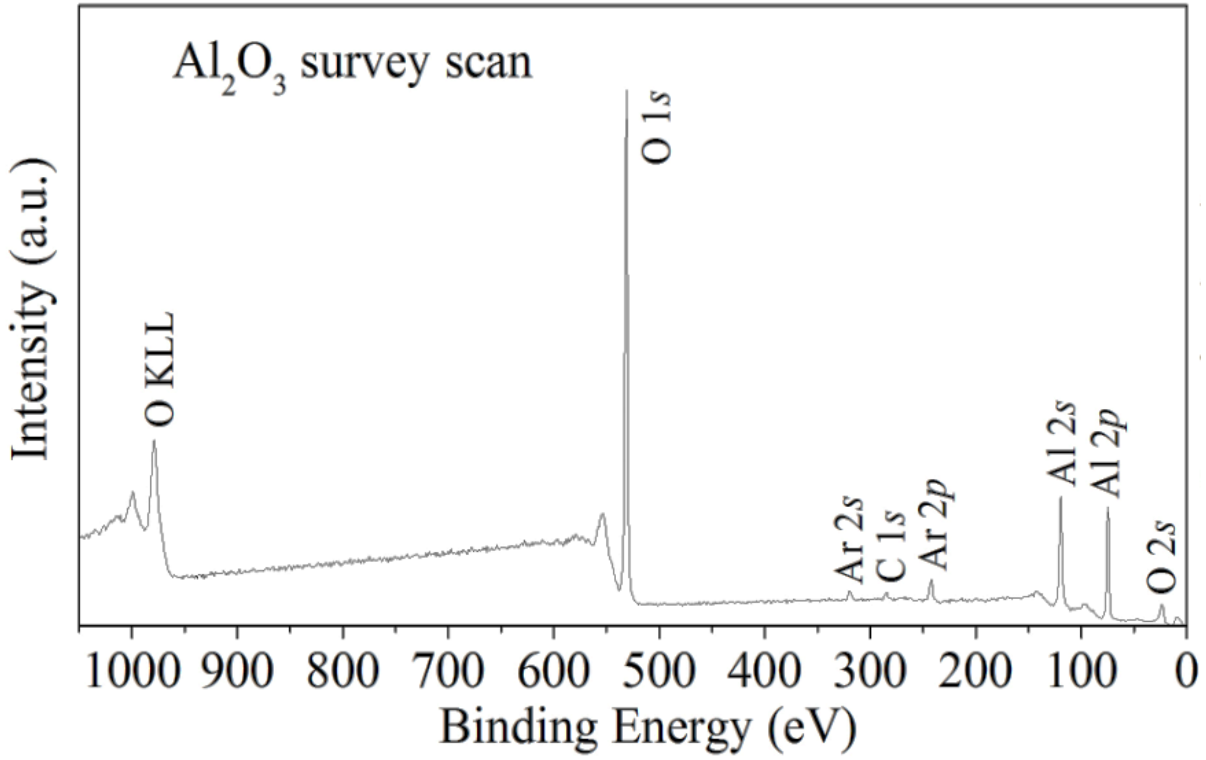
☑ Charge-integration method

☐ Current-profile method

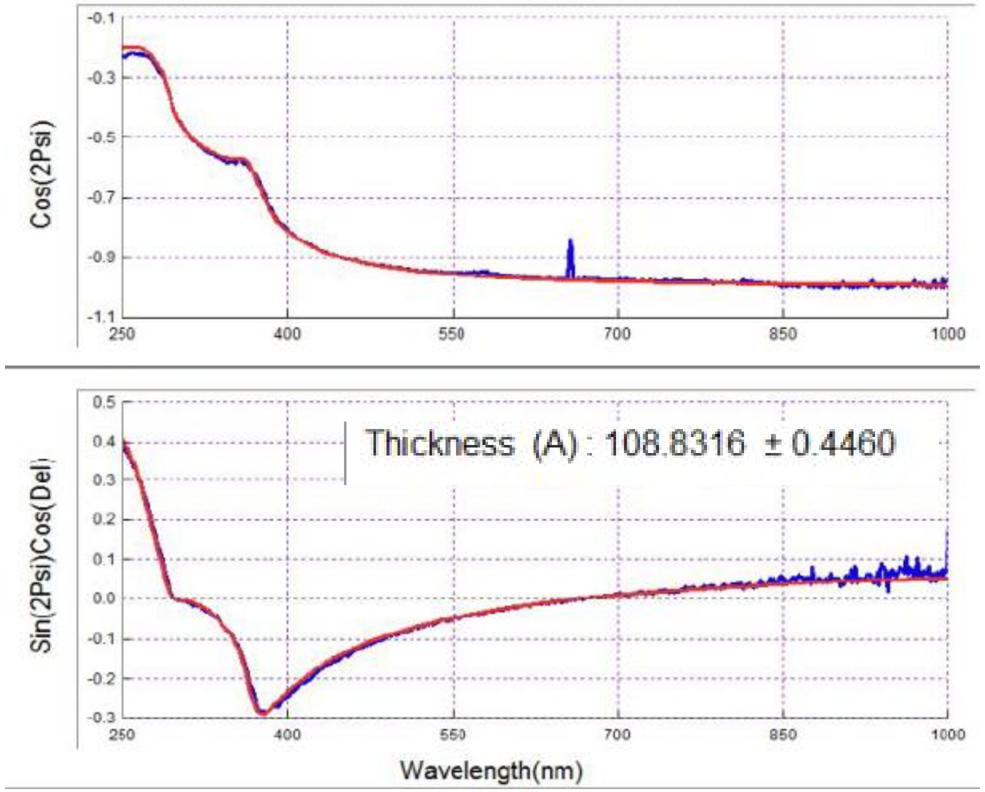
$$\sigma = \frac{\int (I_{col.} + I_{sup.} + I_{inn.}) \cdot dt}{\int (I_{col.} + I_{sup.} + I_{inn.} \pm I_{sam.}) \cdot dt}$$

Results and discussion

❑ Aluminum oxide characterization



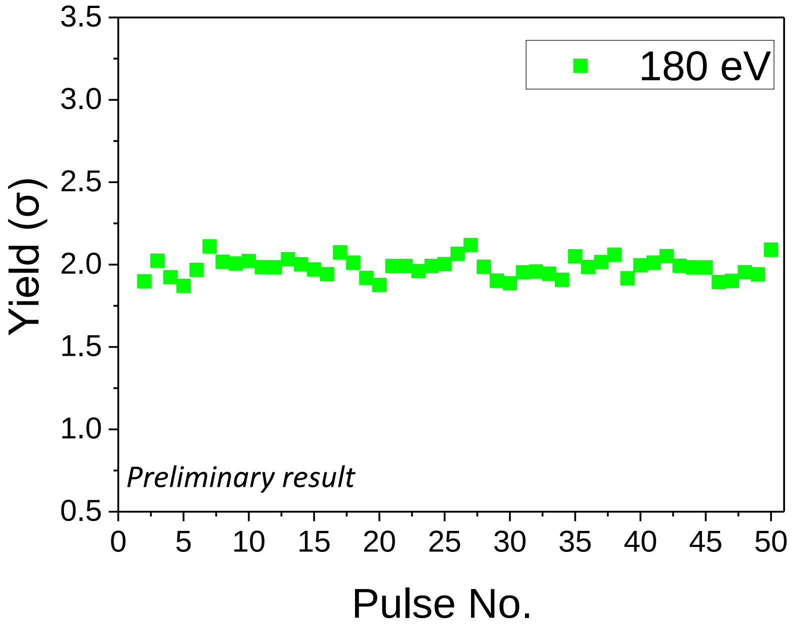
XPS spectra of ALD- Al_2O_3

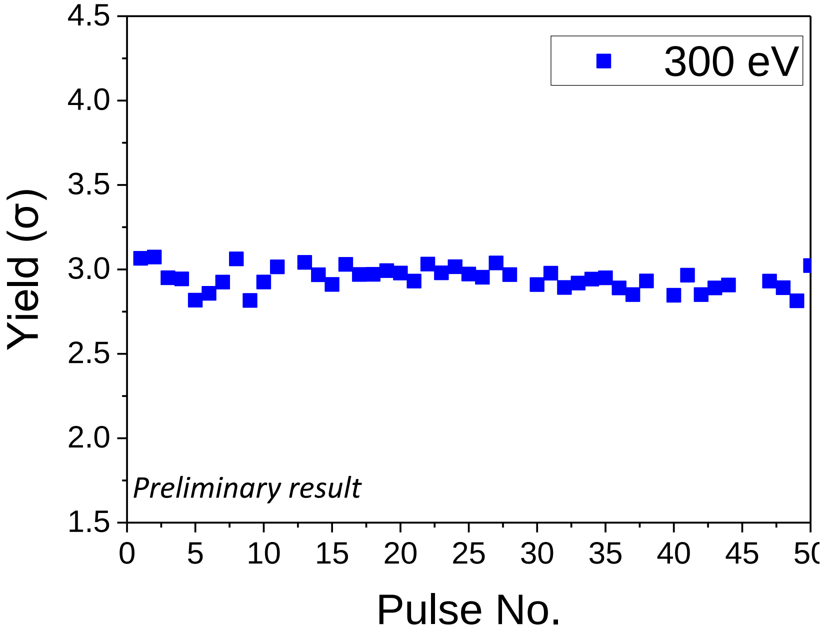


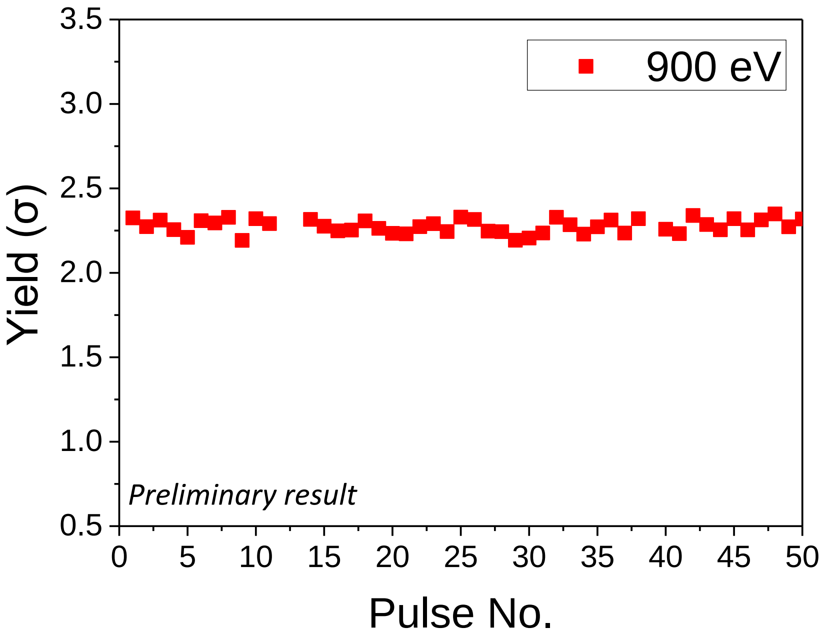
Spectroscopic Ellipsometry

☐Yield vs. pulse No.

50 electron beam pulses with pulse width 20 microseconds, duration 2 seconds

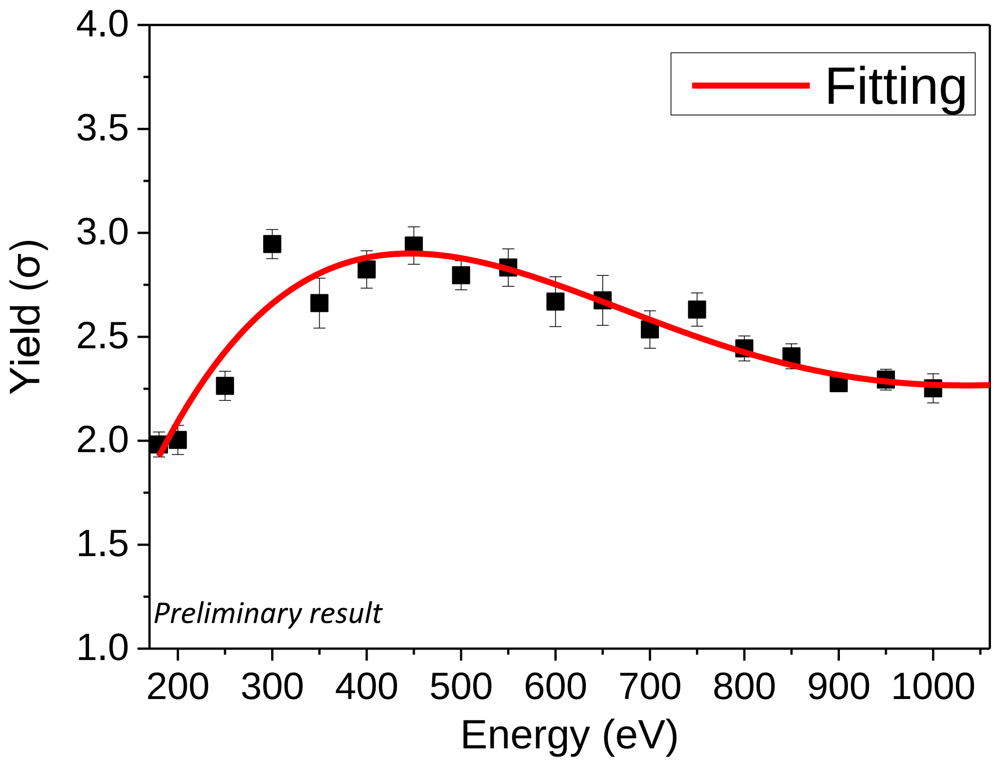




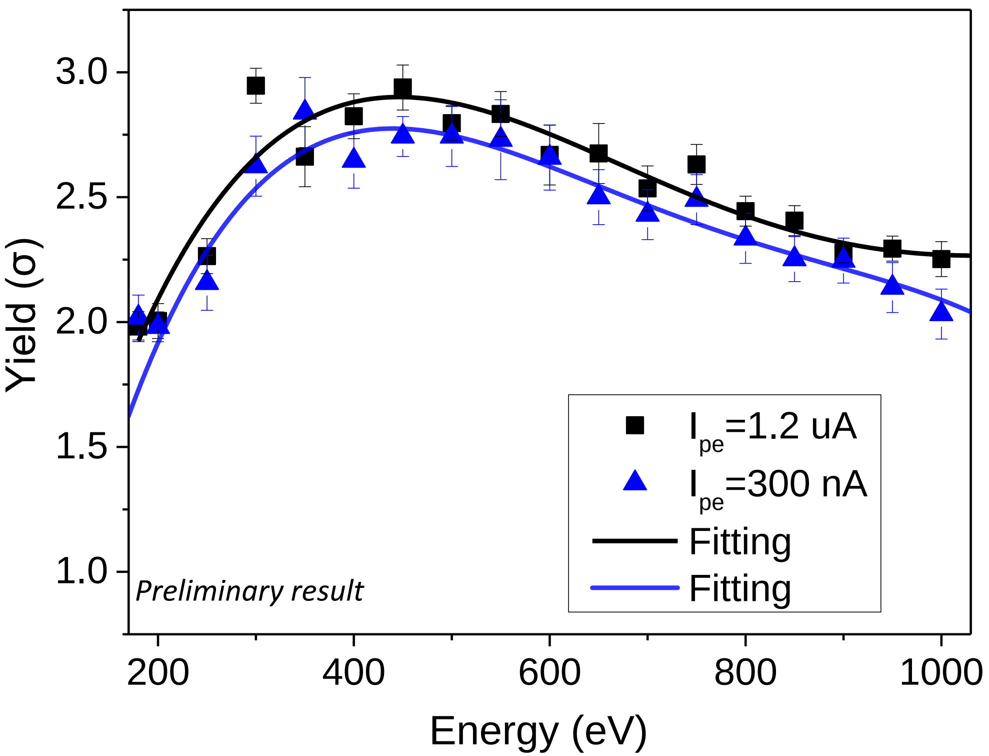


No need neutralization between pulses.

Yield vs. primary energy

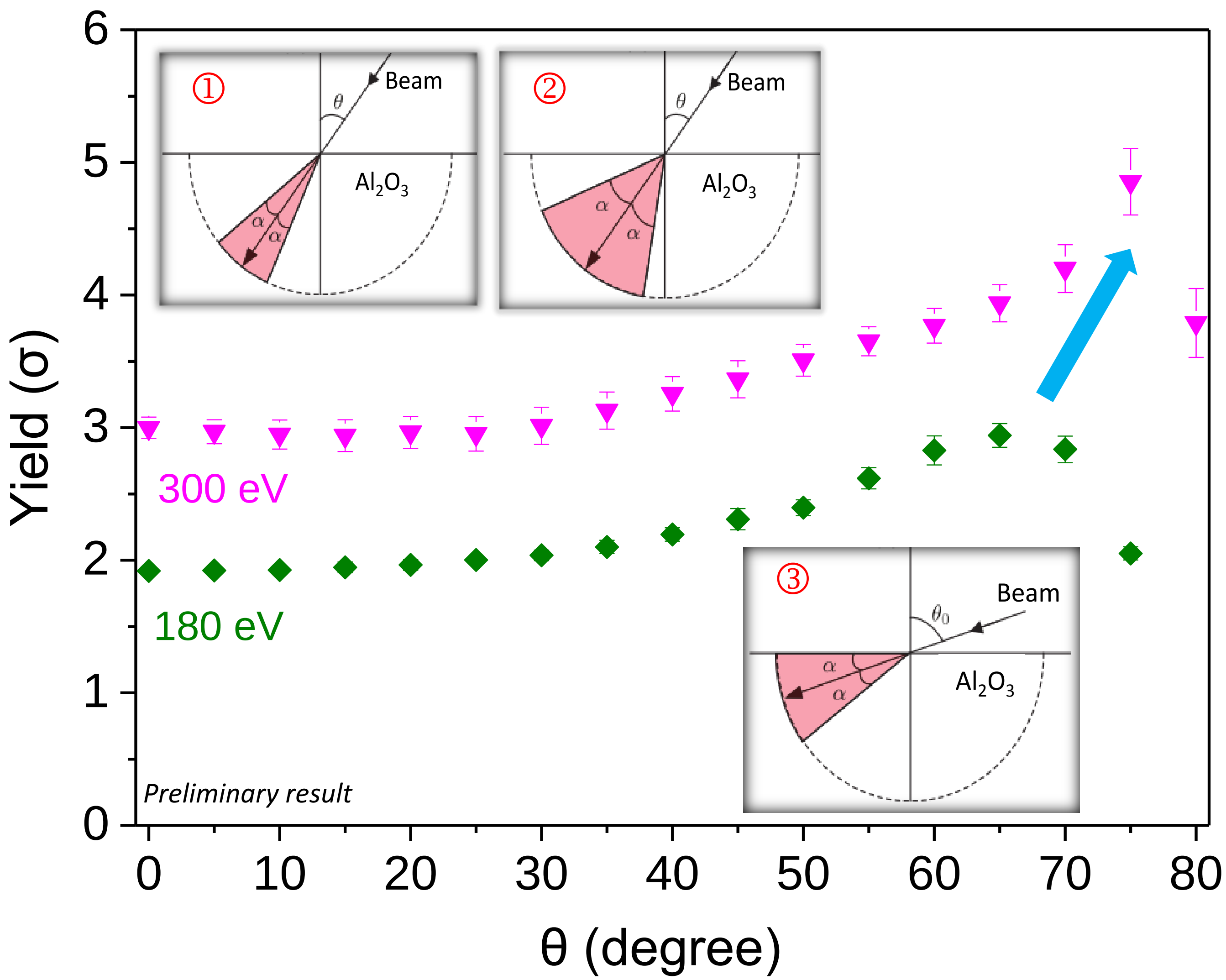


Yield vs. incident current (charge/pulse)



We obtain the typical σ curve for aluminum oxide, in good agreement with previous work.
At the same primary energy, there is obvious difference in yield for two sets of incident current.

□Yield vs. incident angle θ



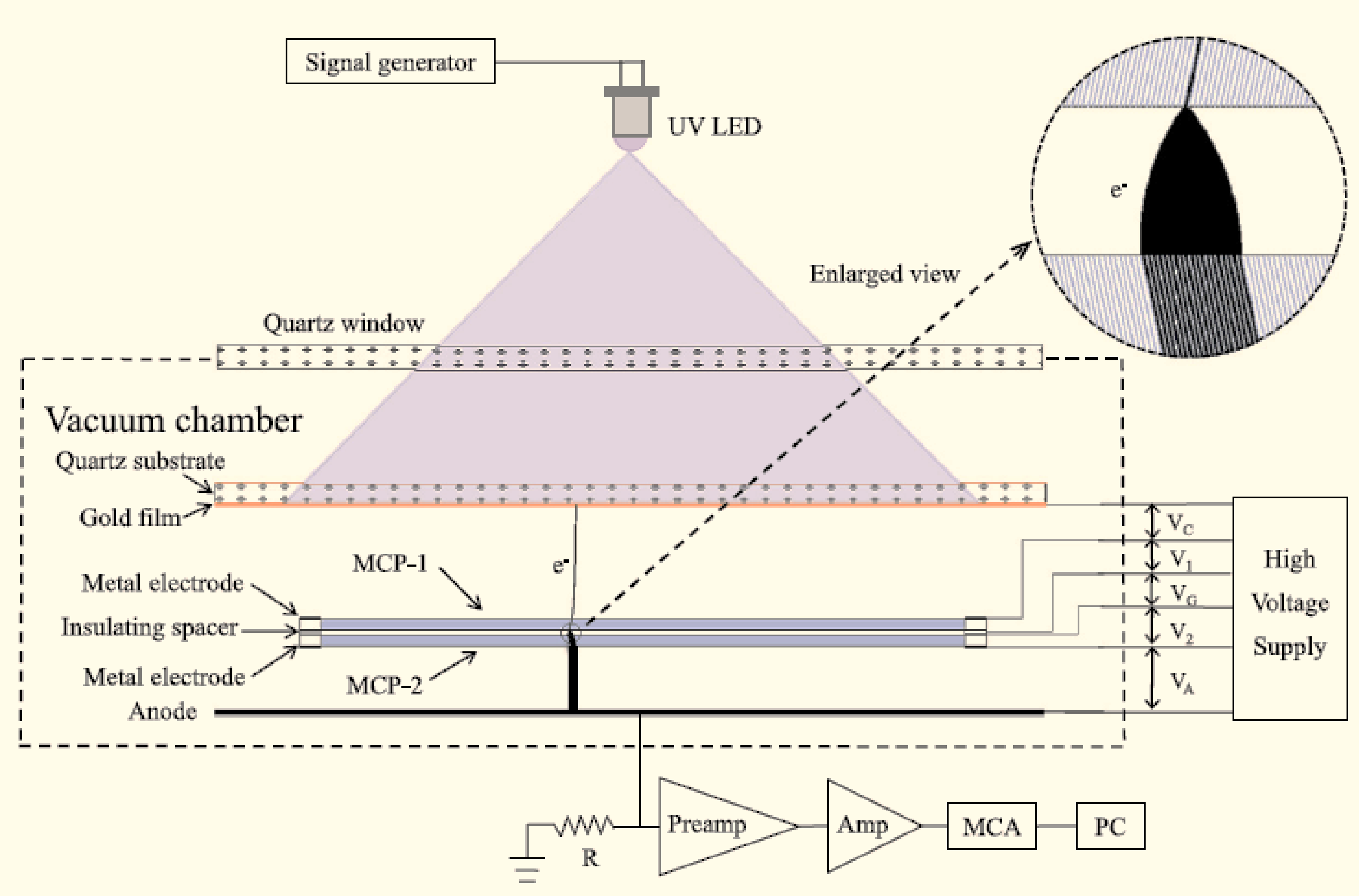
- The yield deviate from the traditional law of monotonic increase with the incident angle.
- The critical angle increases with increasing primary energy.

① The region of the excited secondary electrons is distributed within a certain angle α.

② The smaller the primary electron energy is, the larger the angle α is.

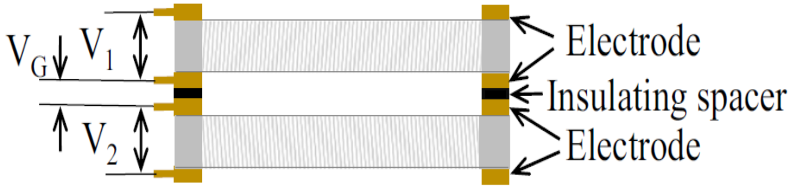
③ With the incident angle increase, the inner secondary electrons are closer to the surface. When incident angle exceeds the critical angle θ_0, the total yield does not rise but decreases.

Application



MCP parameters
OD 32.8 mm, Pore Diameter 10 µm,
Spacing 12 µm, L/d 48:1, Bias angle 12 deg.

MCP assembly configuration



Primary electron energy
Gap voltage V_G
MCPs voltage V_1, V_2

Gain; Resolution; P/V

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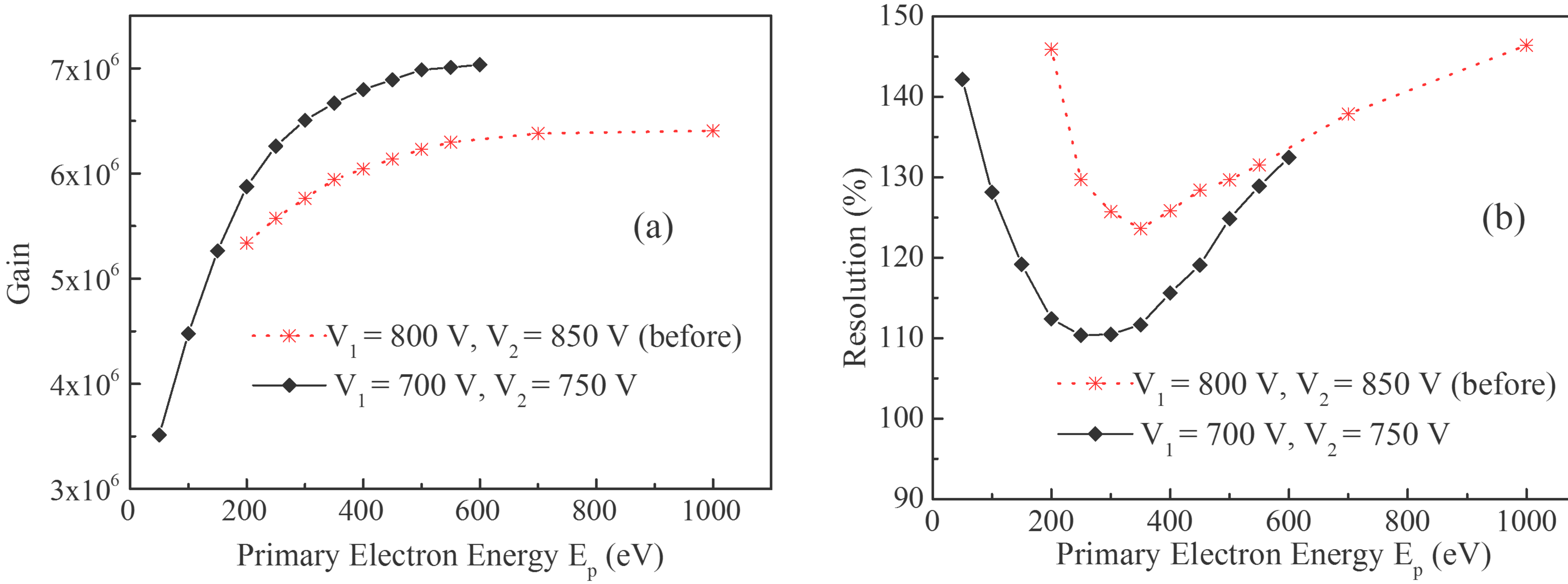
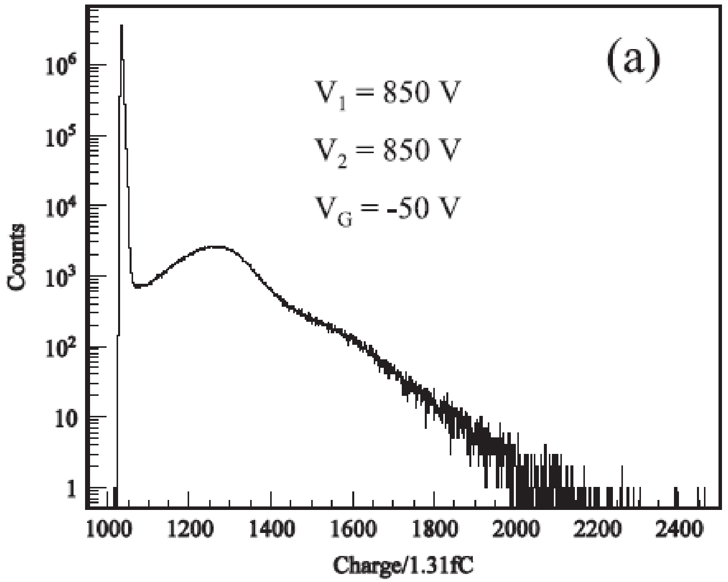
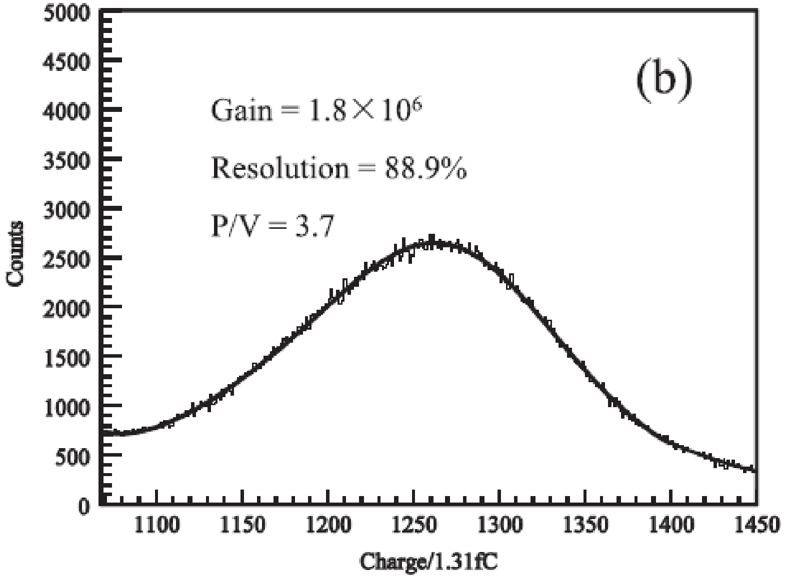
Gain and resolution as functions of primary electron energy



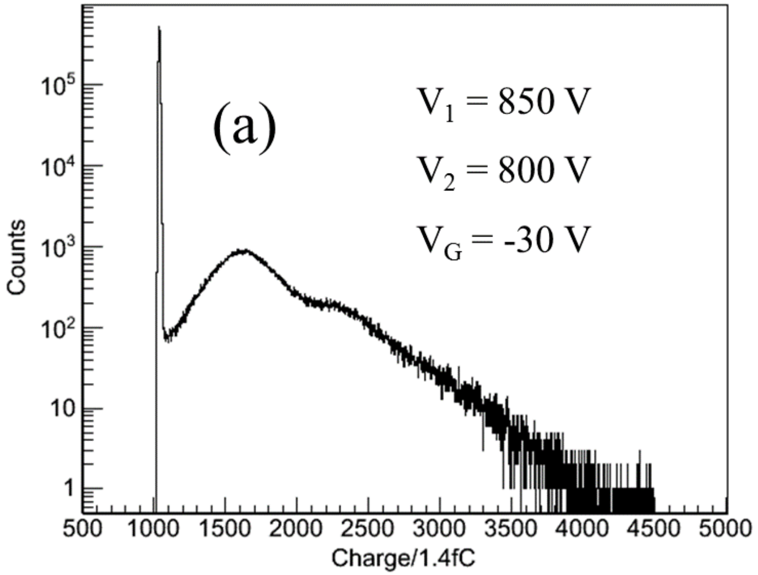
Although bias voltages for coated MCP are 100 eV lower than that of uncoated MCP, the gains of the coated MCP are higher than that of uncoated one. This is due to σ_m is higher for Al_2O_3 than for the lead glass. The resolution also improves for coated MCP.

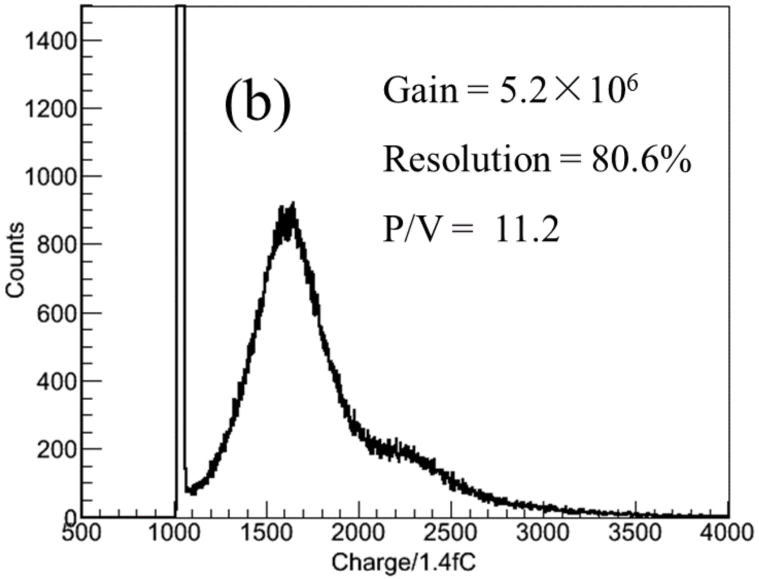
Nuclear Instruments and Methods in Physics Research A (submitted)





Before coating



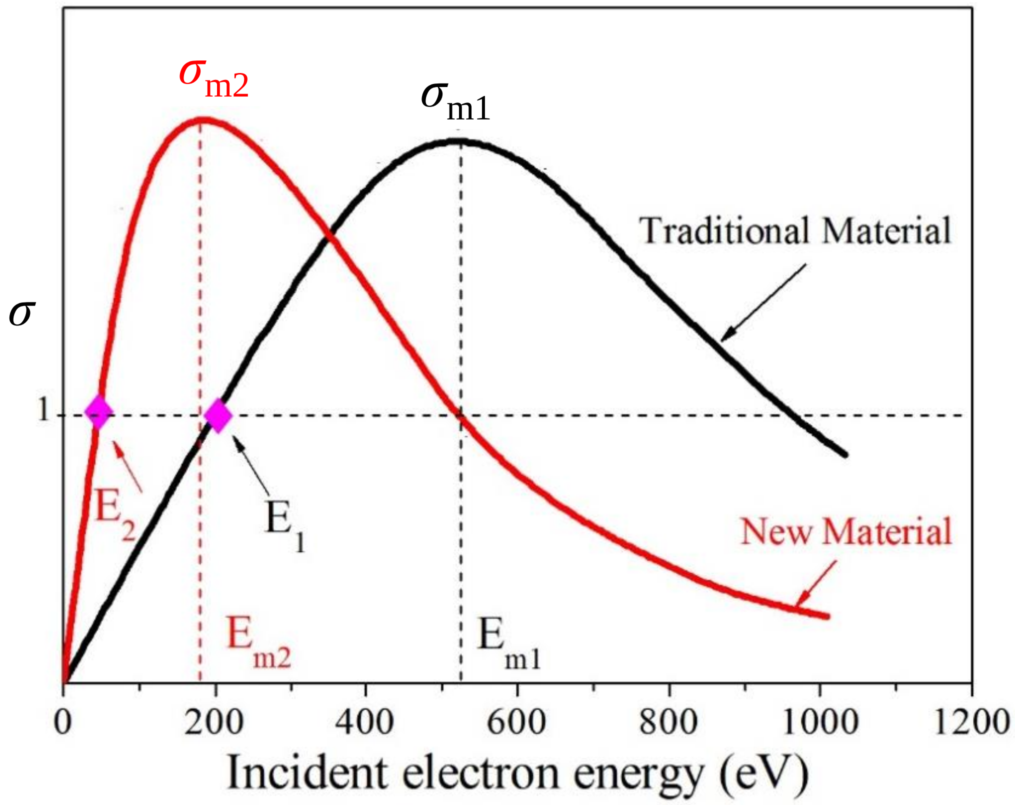


After coating

(a) single electron charge spectrum in semi-logarithmic scale; (b) single electron peak in linear scale.

Challenges Forward

- **Advantages of MCP coated with high σ materials**
  - Reduce MCP bias voltages.
  - Improve gain, resolution and P/V.
  - Long lifetime.
- **Challenges Forward**
  - Improve σ_m of traditional materials.
  - Reduce the E_m as low as possible.



Conclusions and Perspectives

- **The secondary electron properties of nano-thick aluminum oxide have been studied.**
  - **There is no need neutralization between pulses for nano-thick sample.**
  - **There is obvious difference in yield for different incident current.**
  - **When incident angle exceeds the critical angle, the corresponding total yield does not rise but decreases.**
- **The MCP assembly performance improvement through coating aluminum oxide is investigated.**
  - **The gain, the charge resolution and the peak-to-valley ratio of the MCP detector are significantly improved.**
  - **Timing and lifetime performance of coated MCP are studied on the way.**
- **There are two possible solutions to further improve the σ_m with reduced E_m of SEY material.**
  - **Doping and surface modification for traditional material.**
  - **Finding alternative materials and still need to do more study.**

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Thank you for your attention!

Q&A