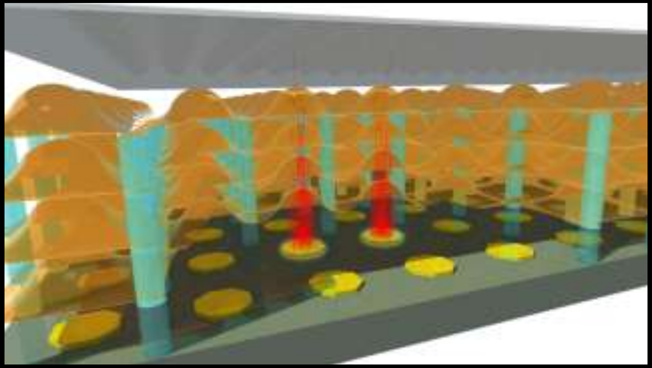
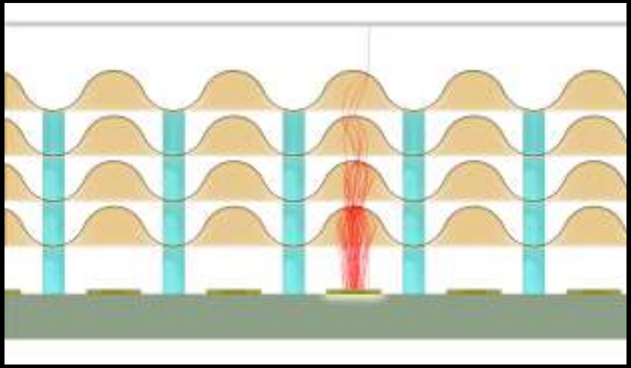
The **Tipsy** single soft photon detector and the **Trixy** ultrafast tracking detector



only ideas: no data



Harry van der Graaf, Jan Visschers, Hong Wah Chan
Nikhef, Amsterdam

Edoardo Charbon, Lina Sarro, Fabio Santagata, Dennis Schaart
Delft University of Technology

IWORID 2012 Figueira da Foz, Coimbra, Portugal
June 4, 2012

Single Soft Photon detectors

Hot booming issue: Silicon Photomultipliers

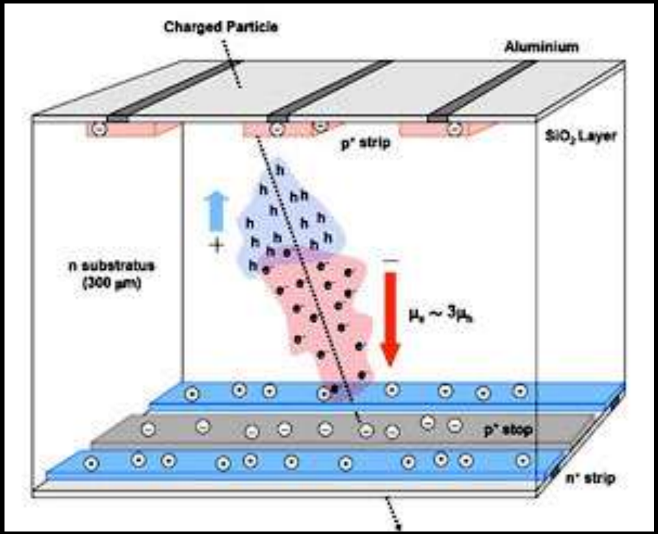
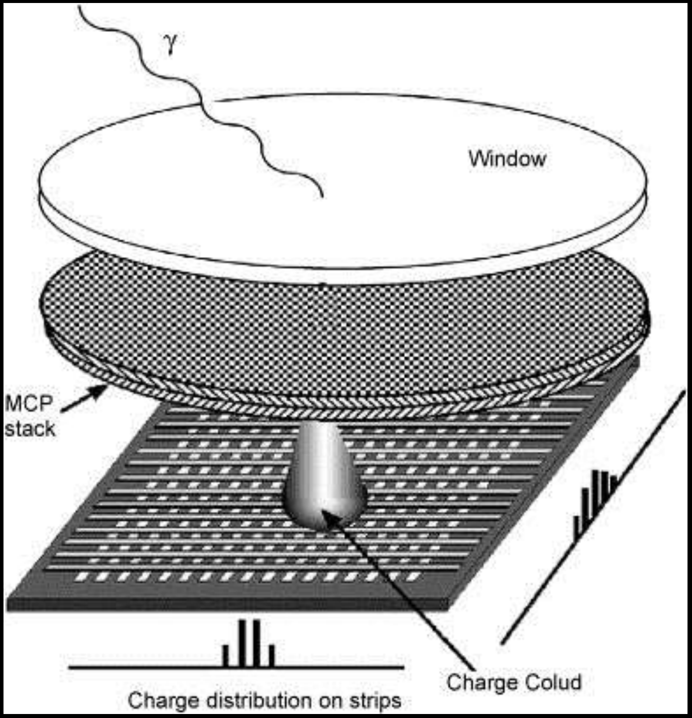


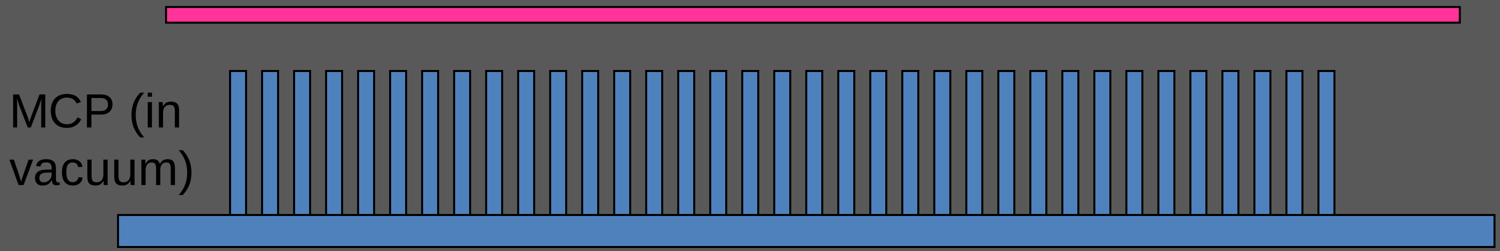
Photo Diodes
Avalanche Photo Diodes APD
Single Photon APD SPAD
Digital SPAD

Other solution:
Micro Channel Plates (MCPs)

Vallerga: MCP + TimePix



Use a MicroChannelPlate MCP?

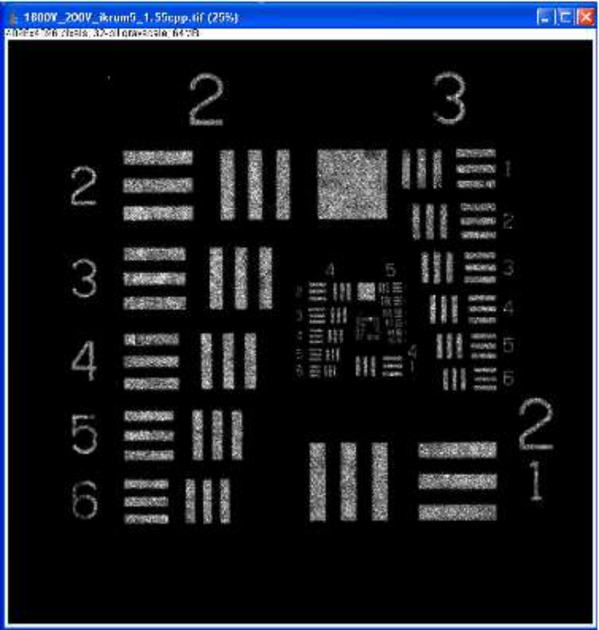


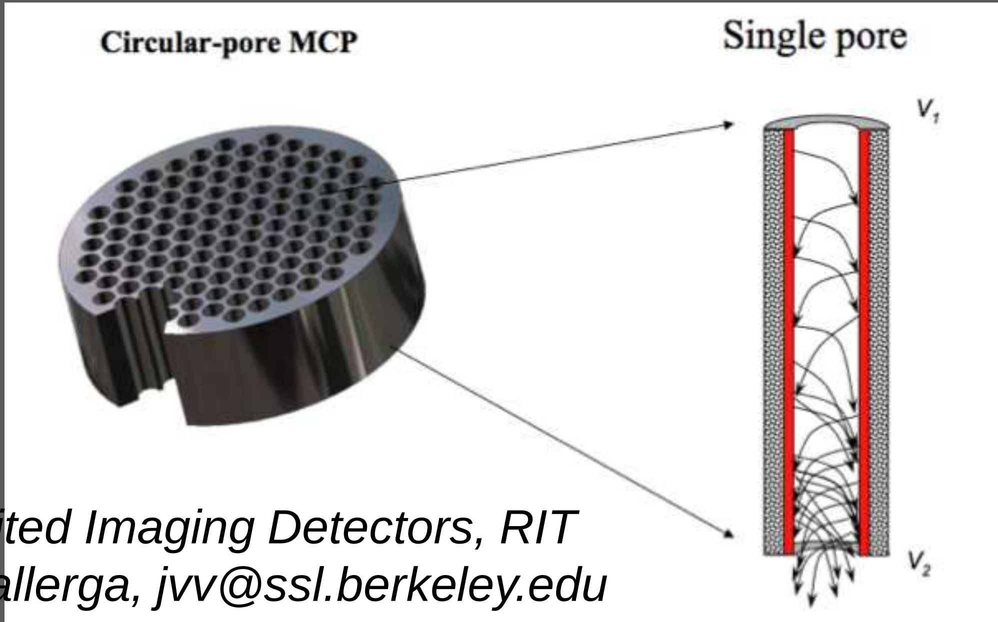
John Vallerga: TimePix + MCPs

We do not know how to make MEMS made MCP.

Problem: aspect ratio of holes

MEMS:micro electron mechanical systems





Quantum Limited Imaging Detectors, RIT 2009, John Vallerga, jvv@ssl.berkeley.edu

Photo Diodes ➔ Single Soft Photon Detectors

Avalanche Photo Diode (APD)
Single Photon Avalanche Diode (SPAD)
Geiger-Mode Avalanche Photo Diodes (GM-APD)
Digital Photon Counters (dSiPMs)
Qupids

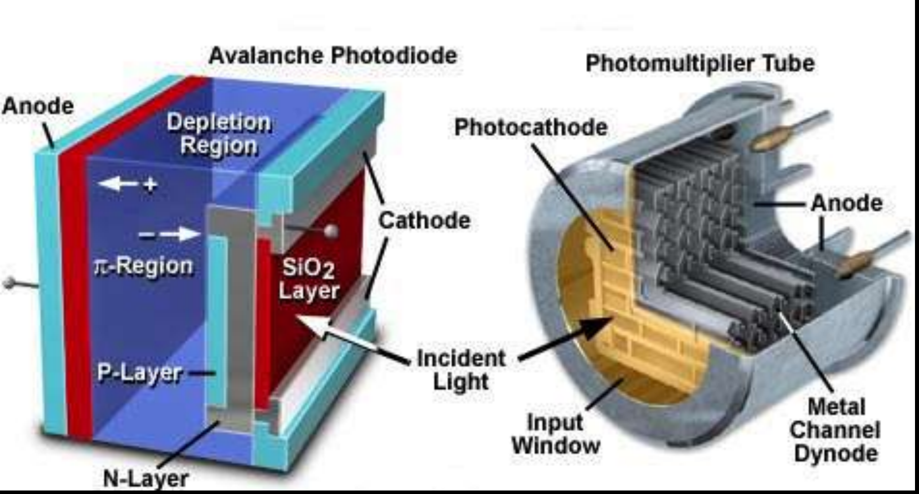
Silicon Photomultipliers

Development: explosive!

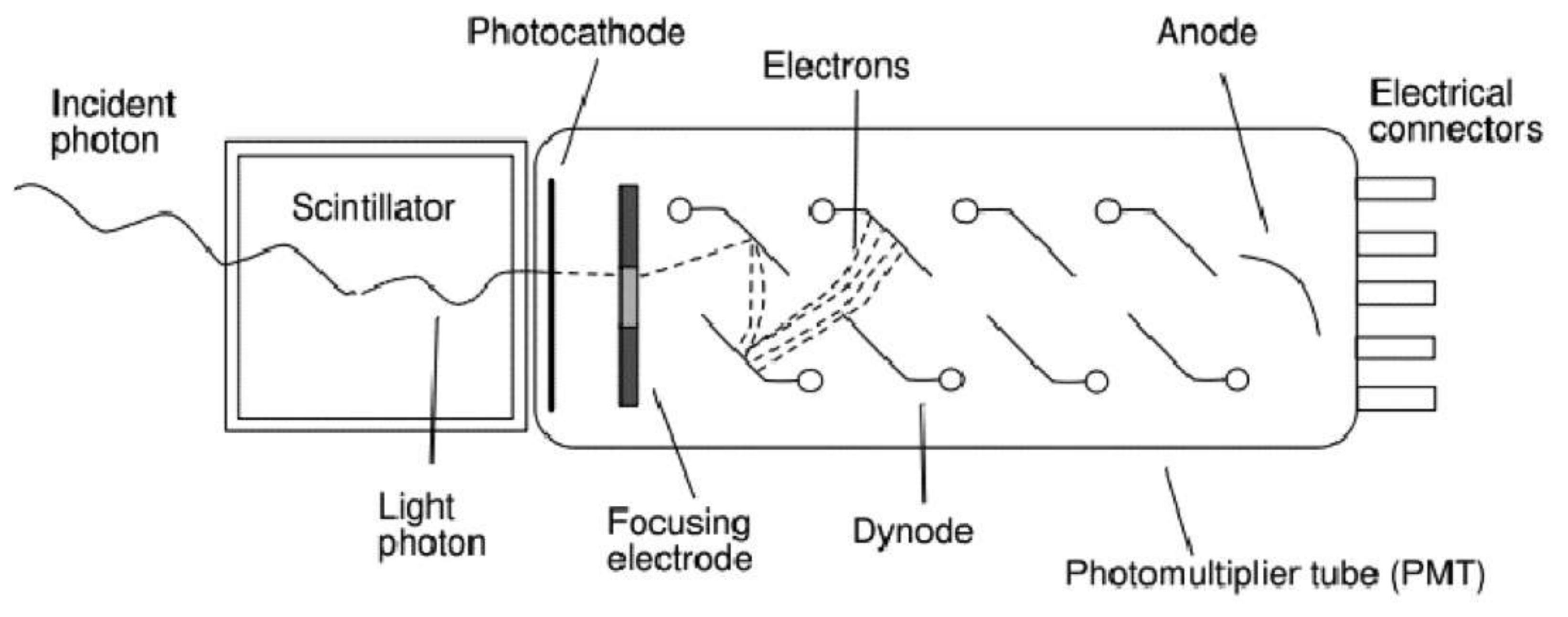
- light, small (planar) volume
- operates in B-field
- low cost
- potential excellent QE

But

- (intrinsic) noisy
- recovery (dead) time
- not rad hard
- (pixel) edge effects QE losses



A very successful photon detector: the Photomultiplier (1934)



- good quantum efficiency
- rather fast
- low noise @ high gain: very sensitive
- little dark current, no bias current
- radiation hard
- quite linear

- voluminous & heavy
- no position resolution
- expensive
- quite radioactive
- can’t stand B fields

Amplification by multiplication: low noise!

Reduce size of dynodes (volume downscaling):

- keep potentials as they were (V_{step} ~ 200 V)

- (non relativistic) electron trajectories same form, but smaller (volume)

- multiplication yield: identical

- 1st dynode: focussing, yield

- pixel input source capacity: only ~ 10 fF

- required gain ~1000 = $2.5^{4\,=}$: 5 dynodes sufficient

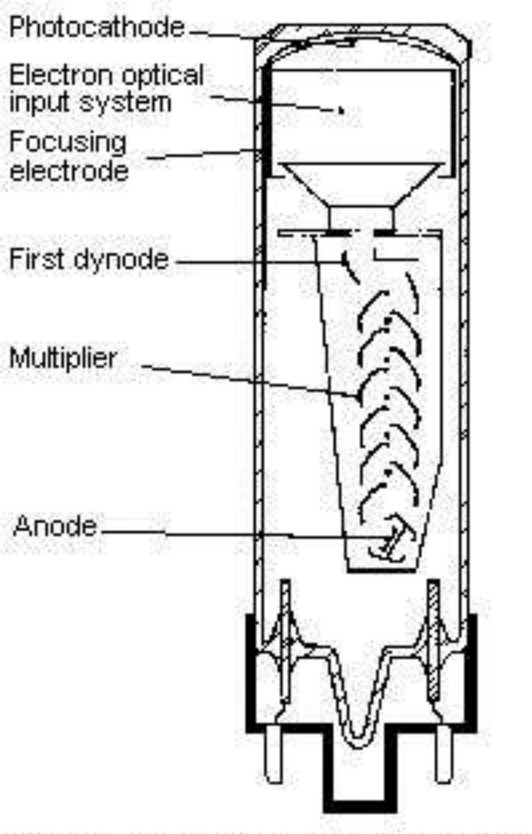
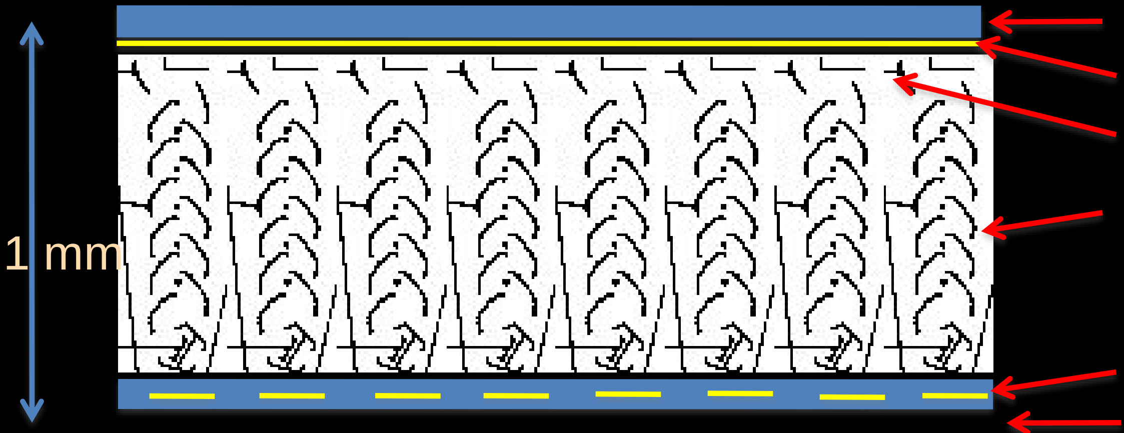


Fig. 8.1. Schematic diagram of a photomultiplier tube (from *Schonkeren* [9.1])

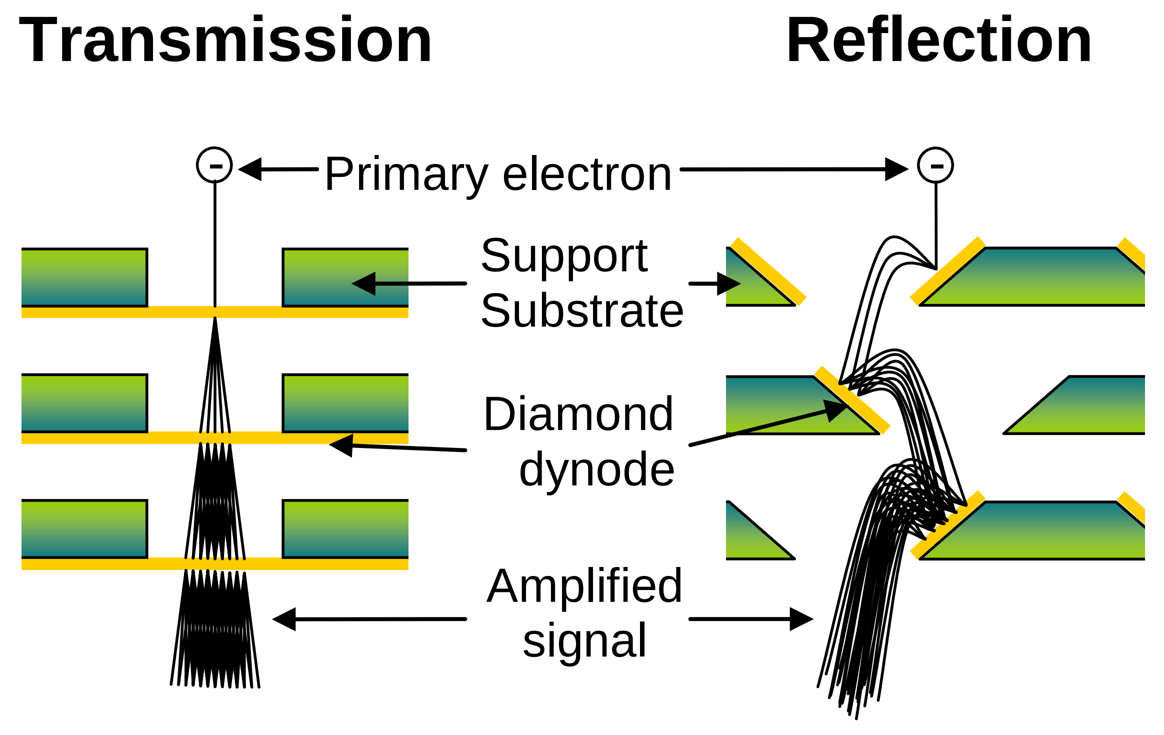
Apply MEMS Technology

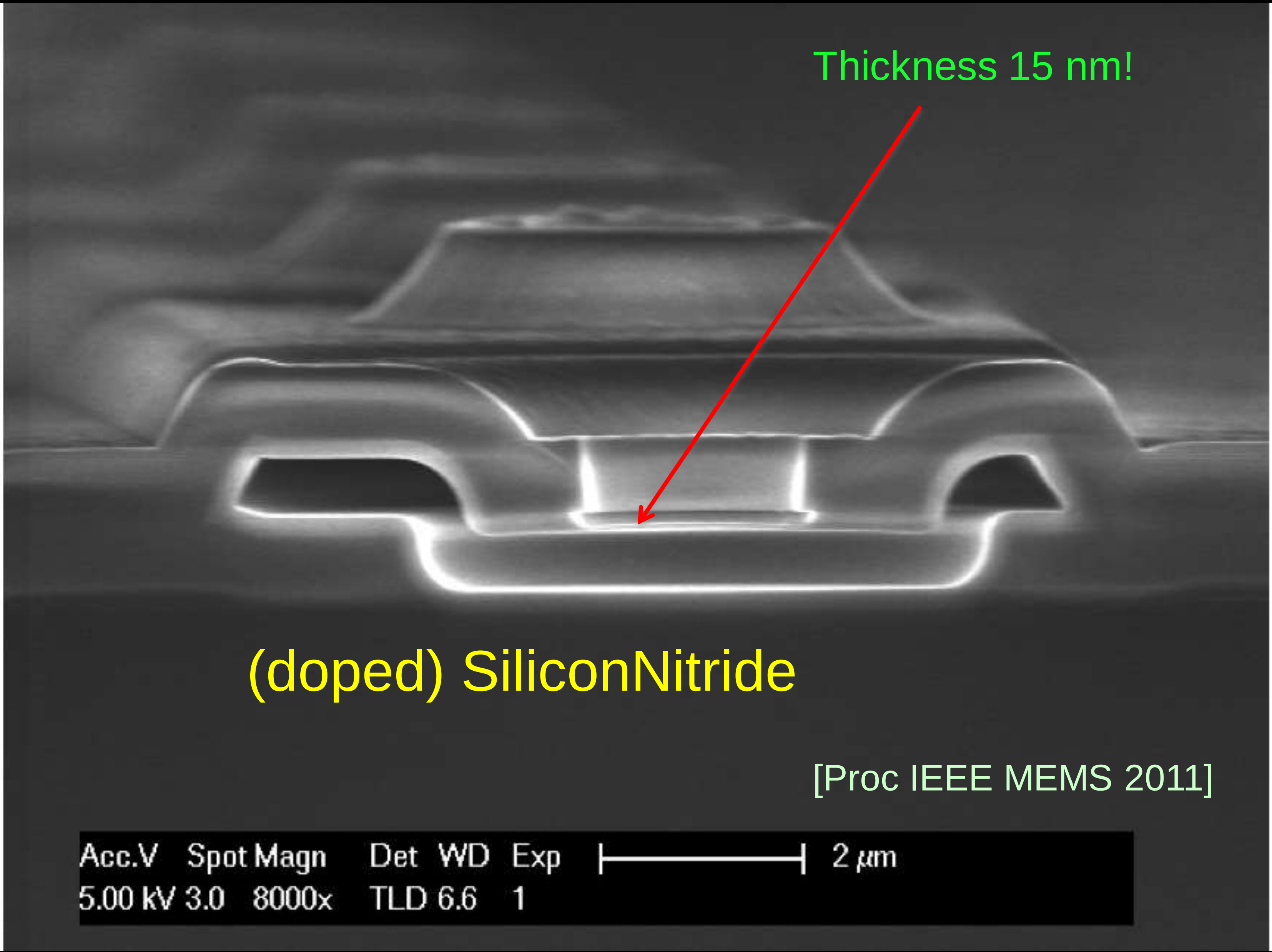


glass window
photo cathode
1st dynode
2nd – 5th dynode
input pads
pixel chip

VACUUM!
No ‘gas amplification’

Diamond detector configurations being investigated





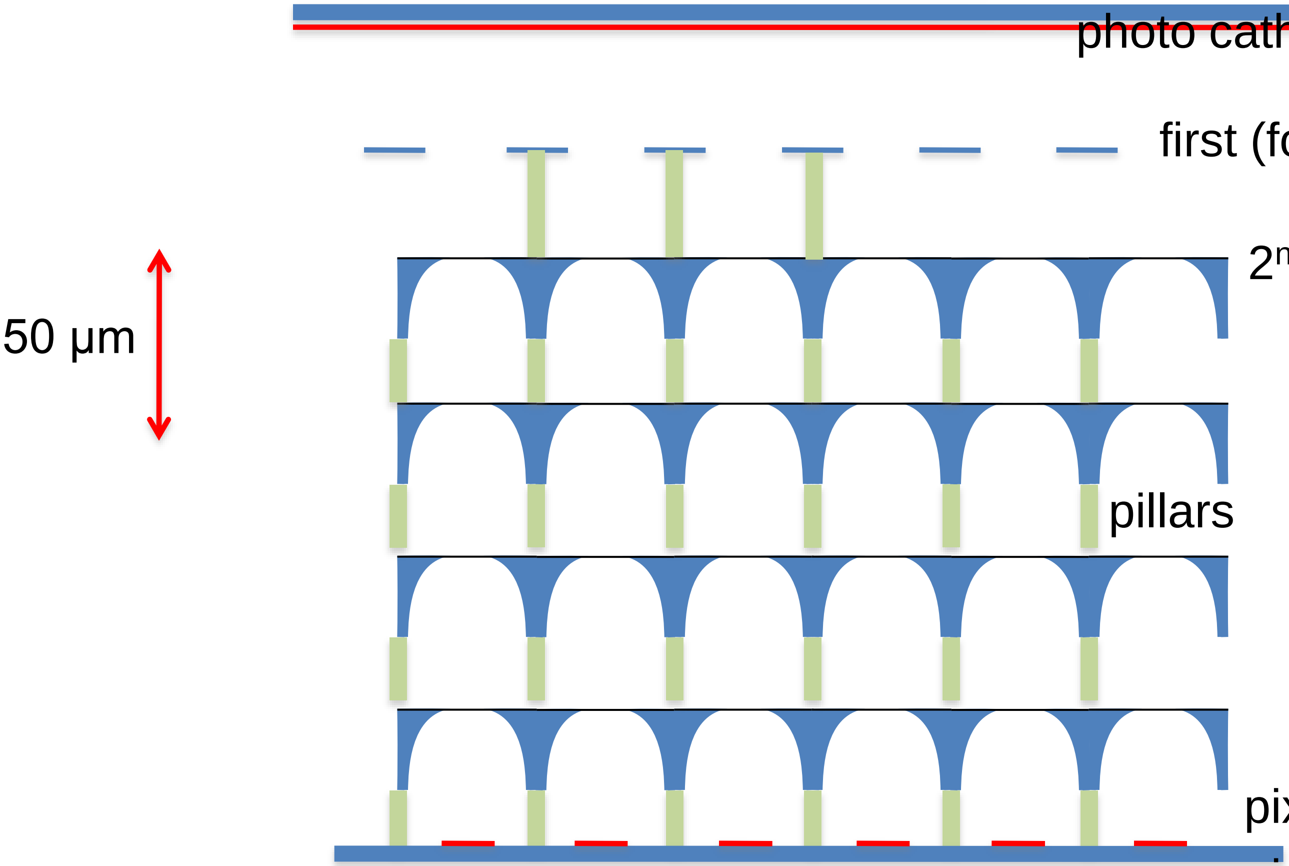
Thickness 15 nm!

(doped) SiliconNitride

[Proc IEEE MEMS 2011]

How to cope with small-area ultra-thin membrane?

Focusing:



glass entrance window

photo cathode

first (focussing) dynode

2nd dynode

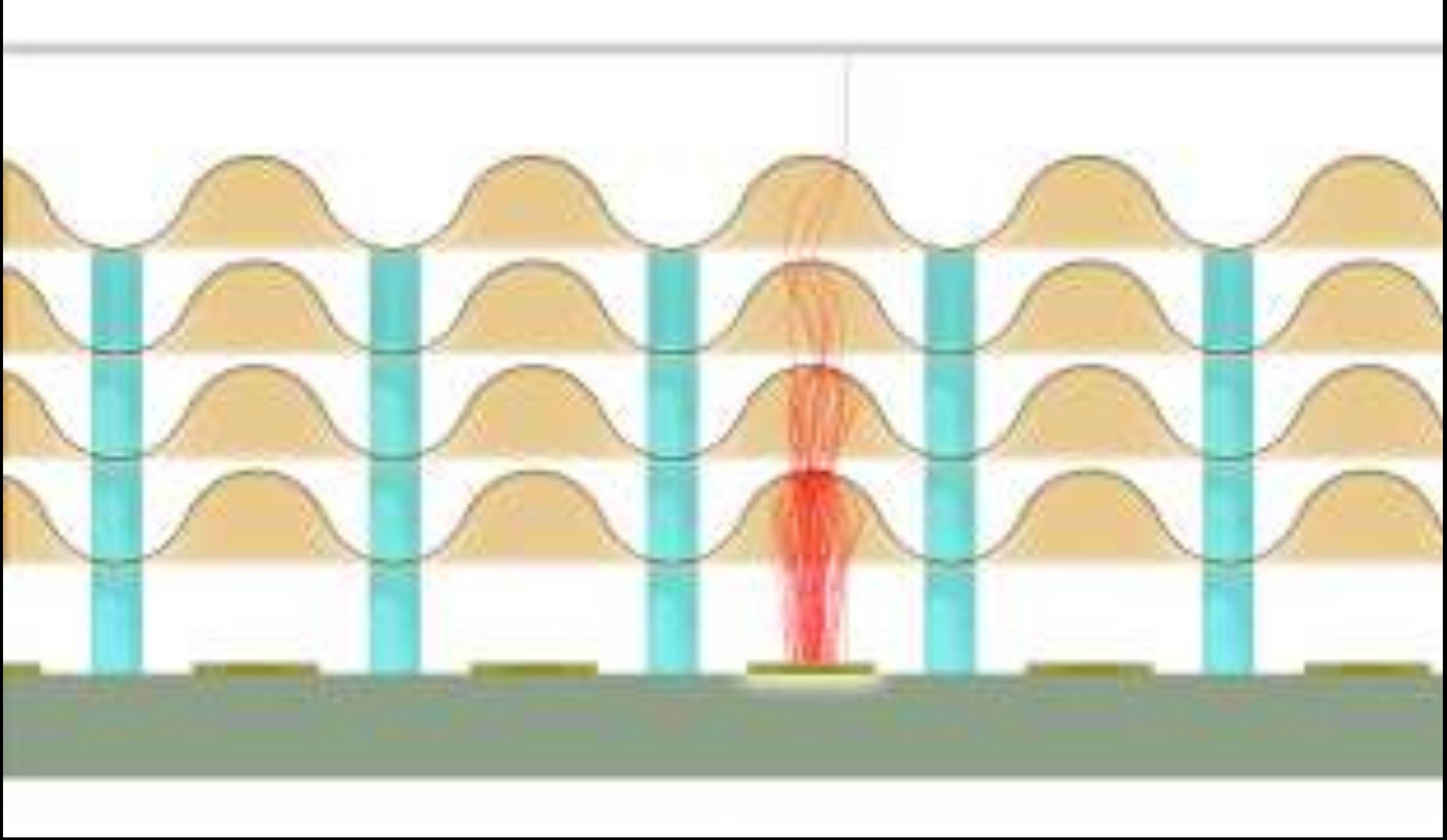
50 µm

pillars

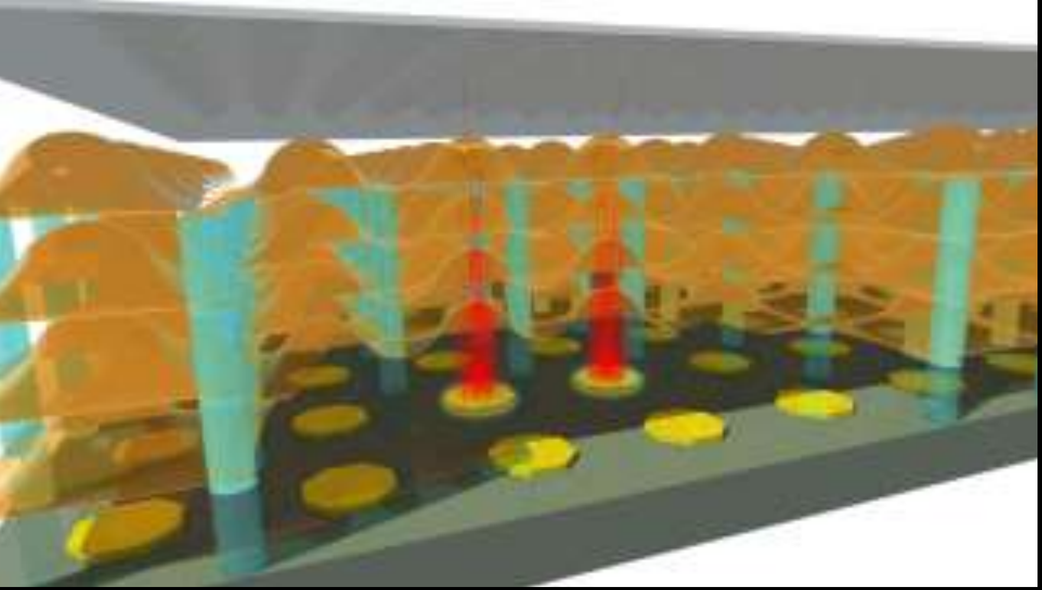
pixel input pads

pixel CMOS chip

‘Colosseum’ structure



Cone shape dynode: focusing electron from above
focusing emitted electrons
mechanically robust: larger diameter cones are feasible



Timed Photon Counter TiPC, Tipsy

Fast: electron mobility is highest for free electrons in vacuum

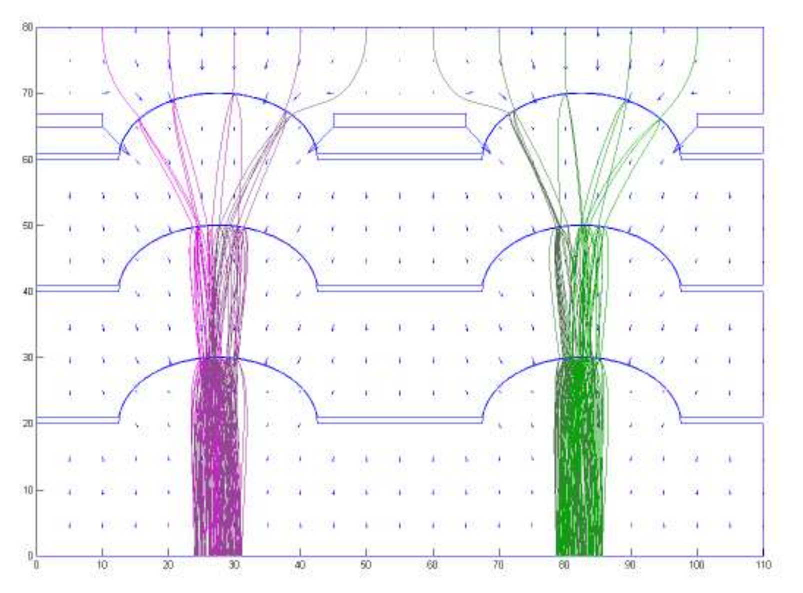
Low noise: no bias current

- Thin, planar, light single soft photon detector
- Electron crossing time t_c = D √ (2 m/qV) = 5 ps for V = 150 V, D = 20 μm
- Electron path: quite straight line towards next dynode
- 30 k e- enough for digital signal on pixel input pads: 7 dynodes adequate
- Signal response after 7 x 5 ps = 35 ps
- Time resolution determined by (last) electron crossing time: ~ 2 ps
- Spatial resolution determined by pixel granularity (55 μm x 55 μm)
- No noise from electron multiplier, no bias current from electron multiplier
- Radiation hard
- Operates in magnetic field

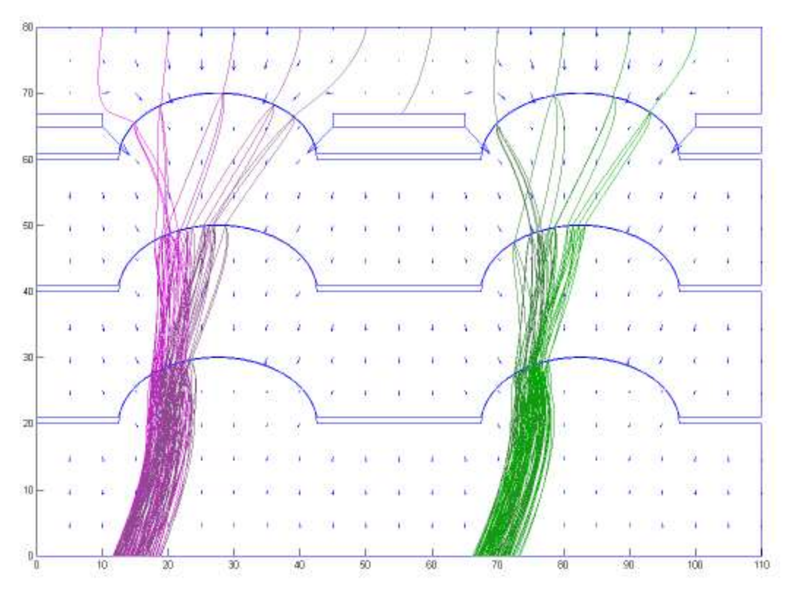
But:

- Secondary electron emission yield not known
- Very strong electric field between dynodes: Fowler-Nordheim limit (10^9 V/m)

First (2D) simulations: influence magnetic field



0 Tesla



1 Tesla

Hong Wah Chan

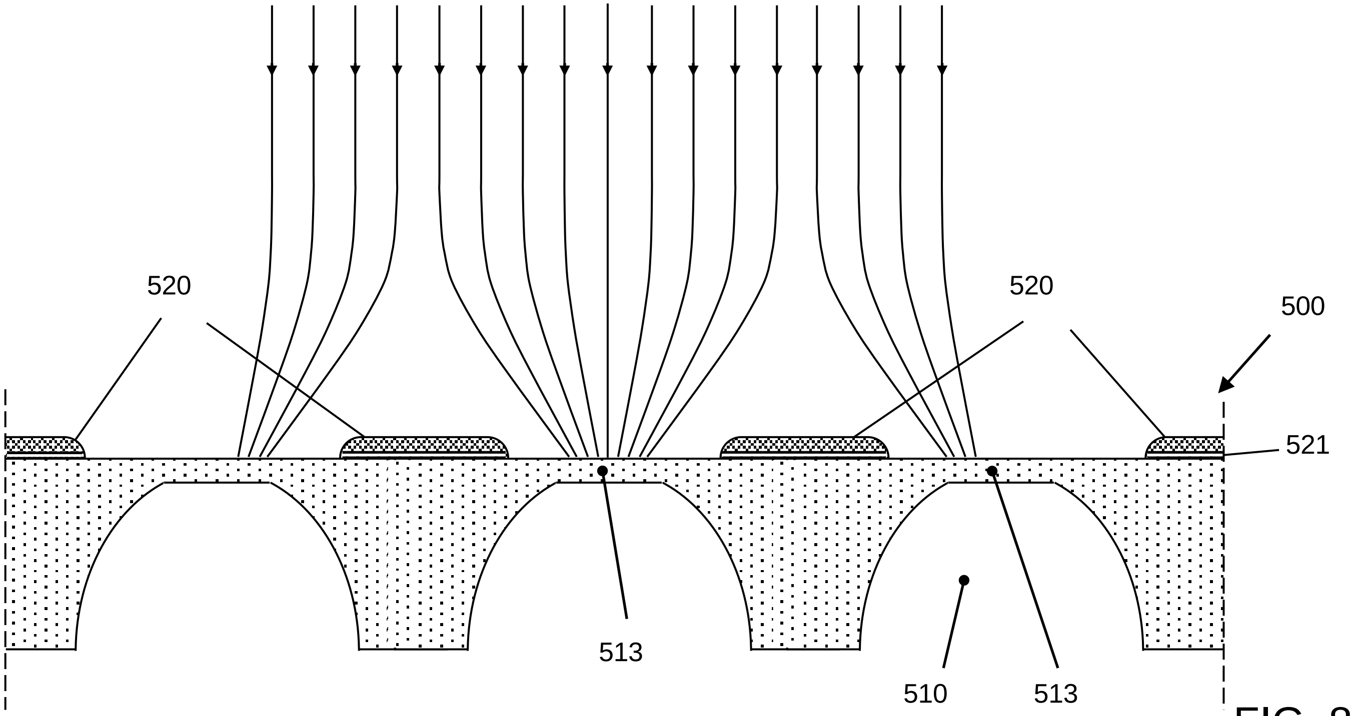
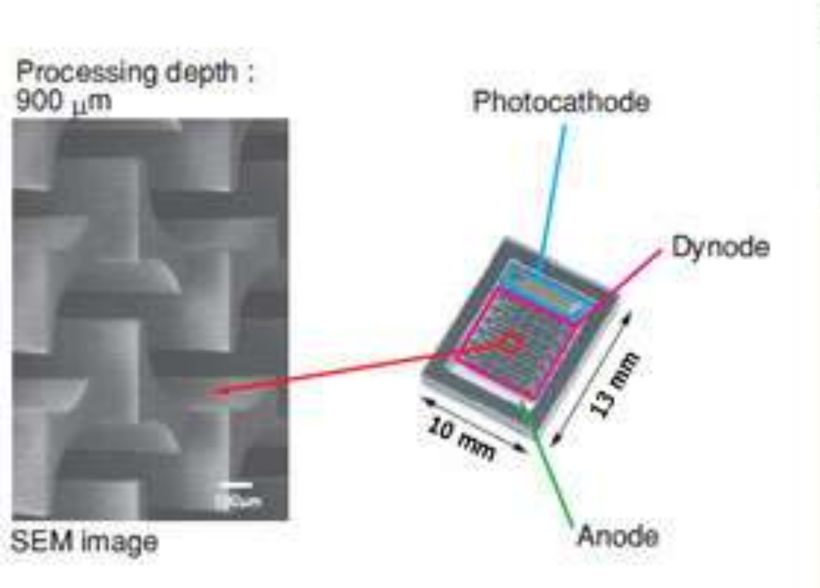
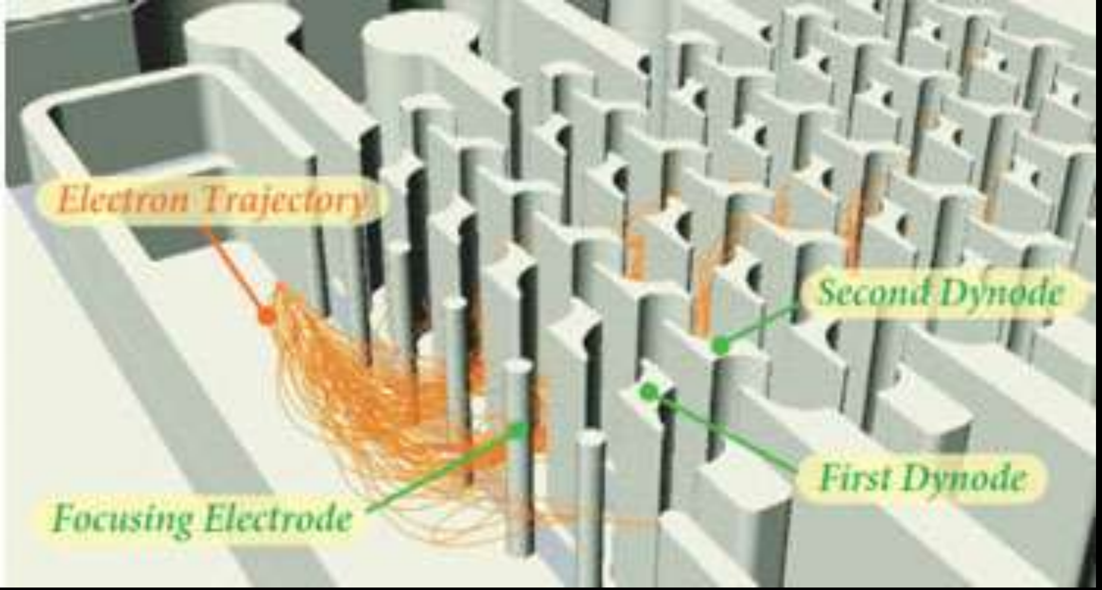


FIG. 8

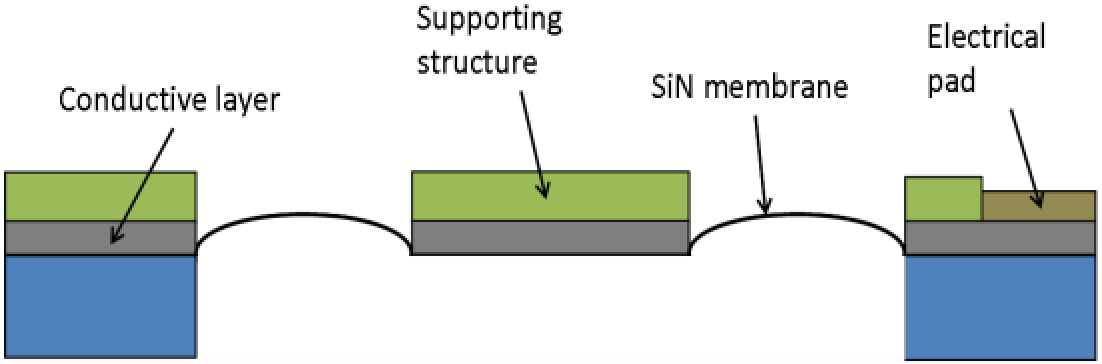
Another solution for focusing onto the first dynode



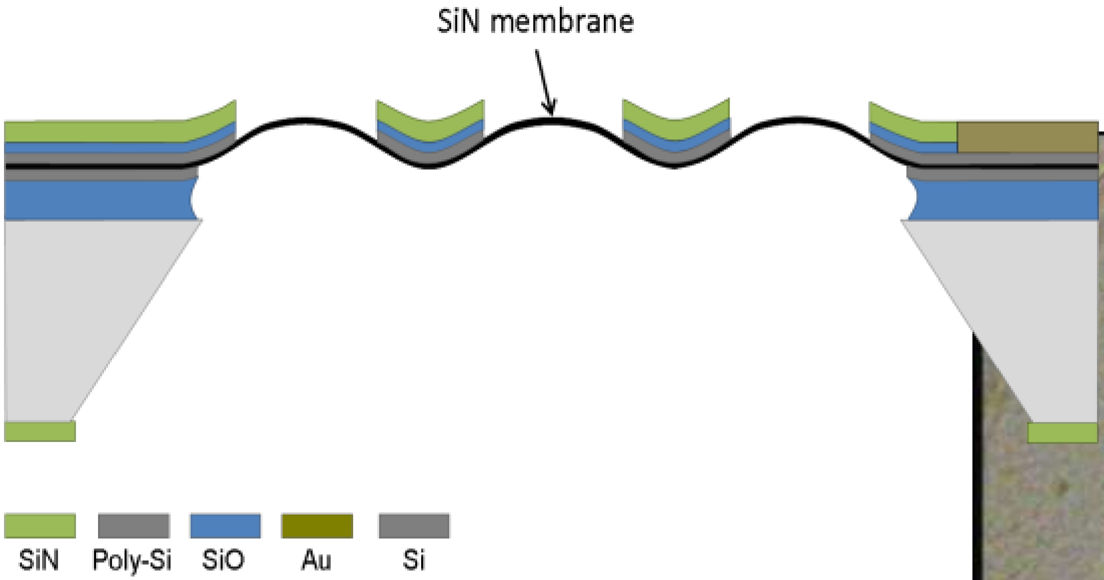


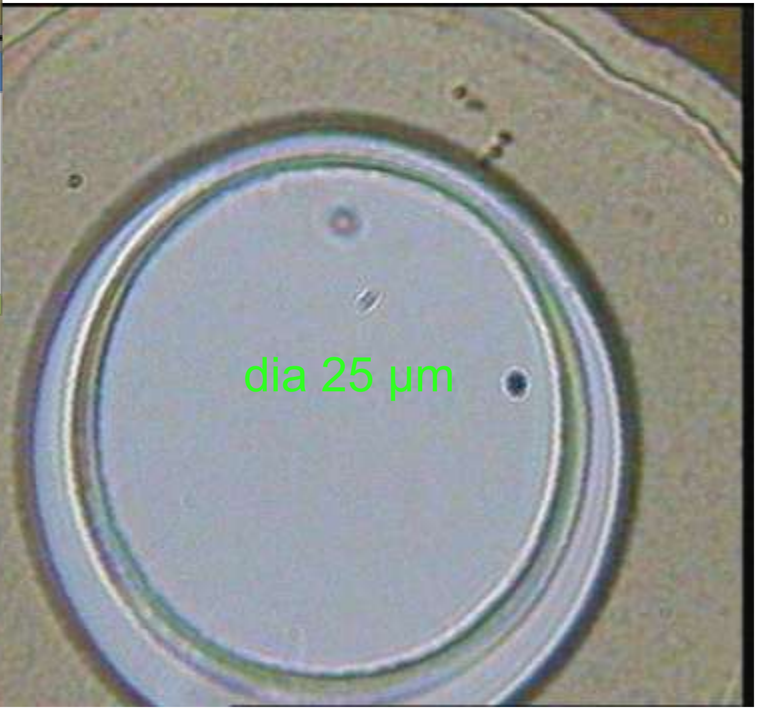
Hamamatsu: the MEMS made µPMT

- Small dynode geometry as in Tipsy
- announced µPMT in 2010: not yet available…….



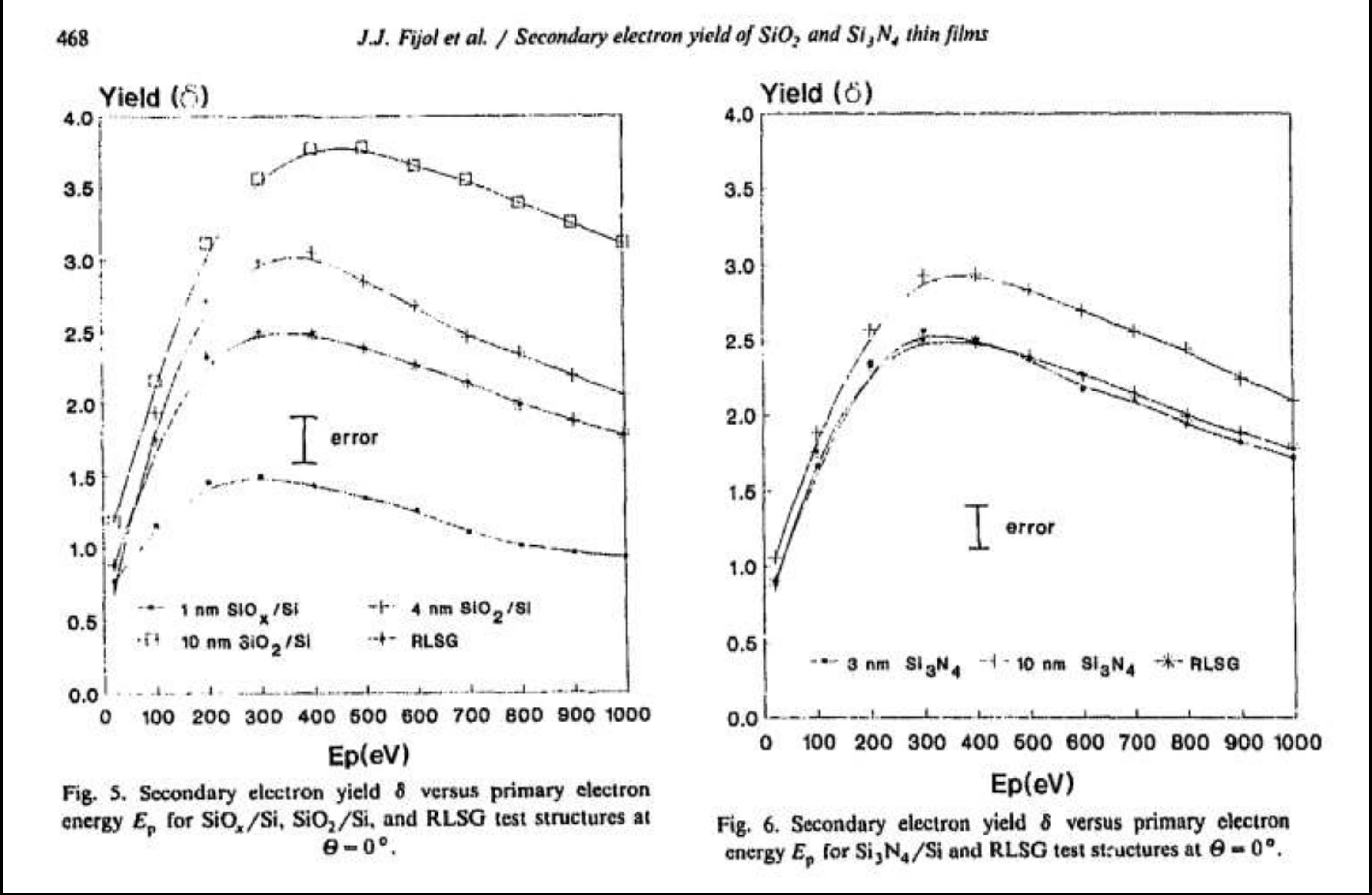
Fabio Santagata
Lina Sarro
Hong Wah Chan





15 nm thin dynode material
Si Rich SiNitride (SRN)

First realistation of transmission dynode @ DIMES, Delft University of Technology



468 *J.J. Fijol et al. / Secondary electron yield of SiO_2 and Si_3N_4 thin films*

Fig. 5. Secondary electron yield δ versus primary electron energy E_p for SiO_x/Si, SiO_2/Si, and RLSG test structures at $\Theta = 0°$.

Fig. 6. Secondary electron yield δ versus primary electron energy E_p for Si_3N_4/Si and RLSG test structures at $\Theta = 0°$.

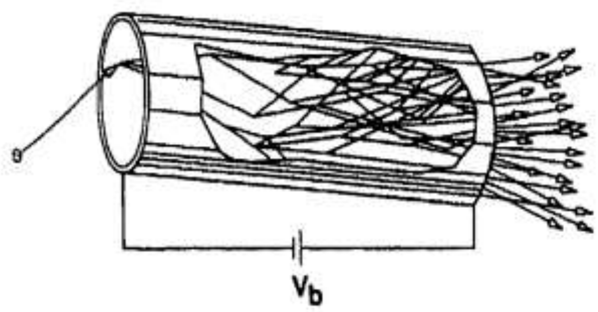


Fig. 1. Schematic of geometric electron multiplication in a straight-channel electron multiplier under bias voltage V_b.

Secondary electron emission yields of SiNitride: Fijol et al.

Measurements: Vacuum set-up with electron gun in preparation

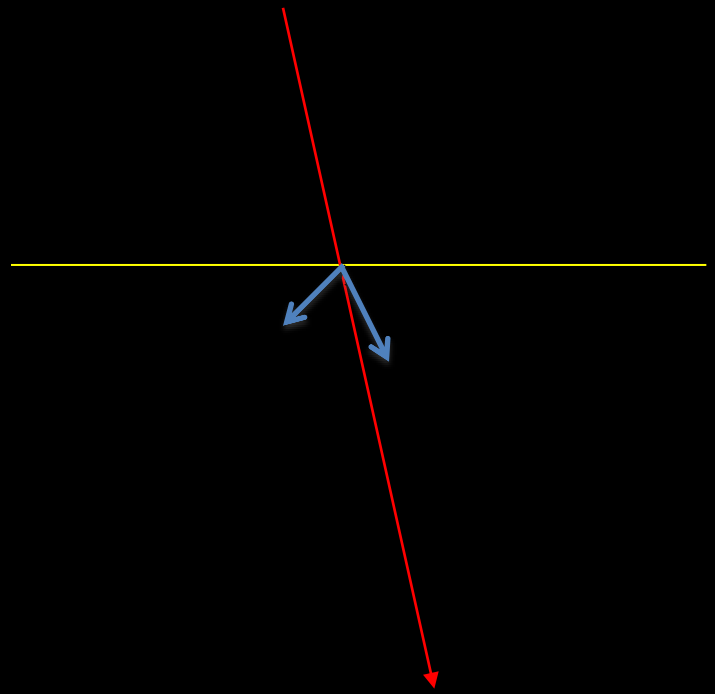
Measure e-beam current and currents to/from dynode and anode

For tracking of fast charged particles (MIPS):

Replace photocathode

(depleted Si or gas) by: **Electron Emission Membrane**

Emits (at least one) electron at the crossing point of membrane surface and MIP, with a high probability, in vacuum



electron emission membrane

aluminium foil:

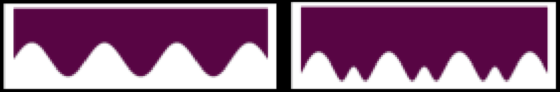
- at least 1 electron is emitted in 4 % of the cases
- energy of electron: 0 – 5 eV
- probability depends on surface condition
- increase to 6 % if layer of AlOxide is present

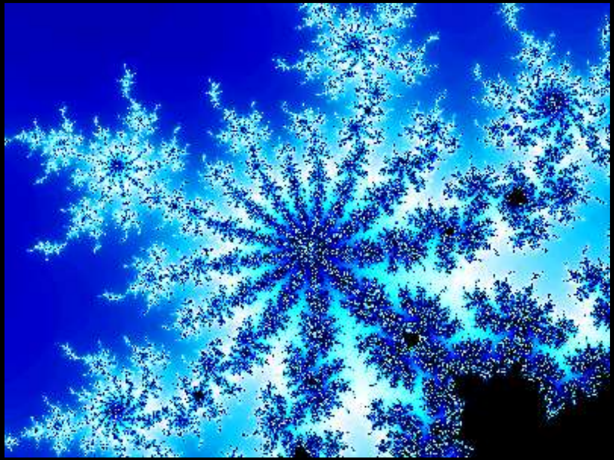
Electron Emission Membrane

Issue: to reach a high yield (prob. to emit at least one electron) > 80 %

1. low work function material (low exit potential)
   Plain aluminium foil: 4 – 6 % yield

2. Surface enlargement
   Skin effect: only ~ 50 nm
   surface layer participates to yield

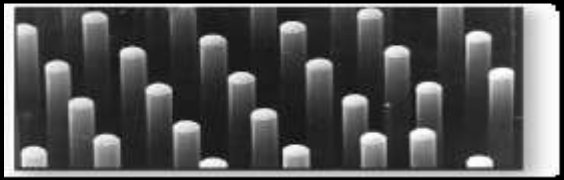


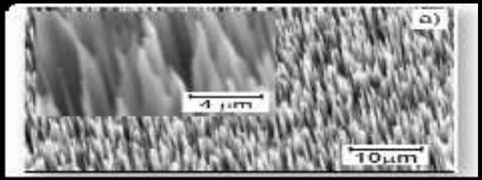


Fractal

3. Field assistance
   (depletion layer)

4. Strong extracting E-field





nano grass

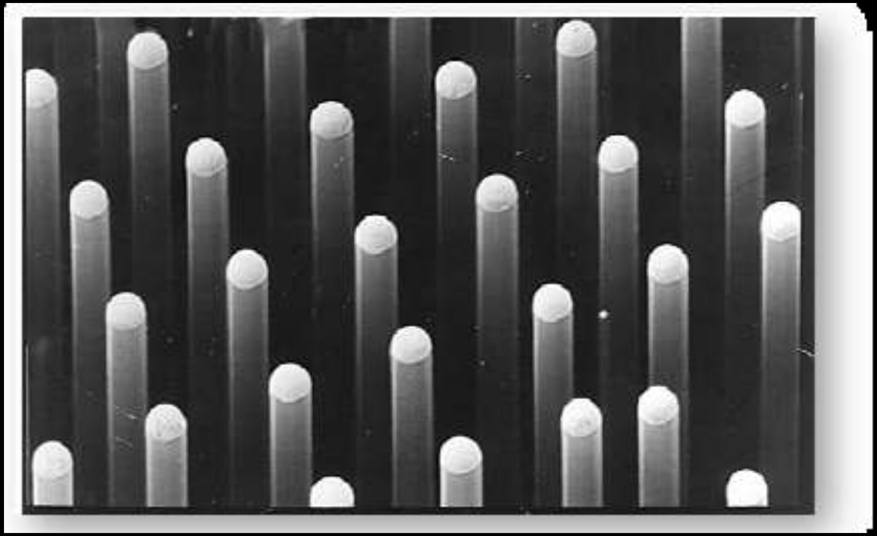
…..needs solid state (theoretical) physicists…..

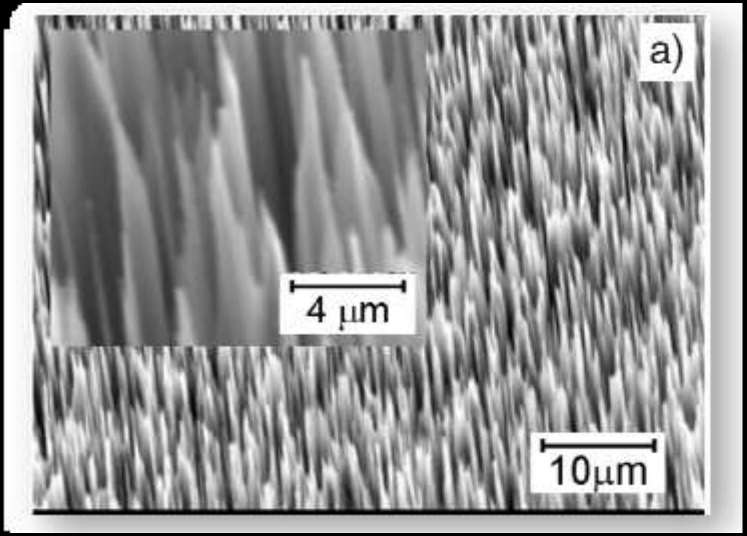
Work function

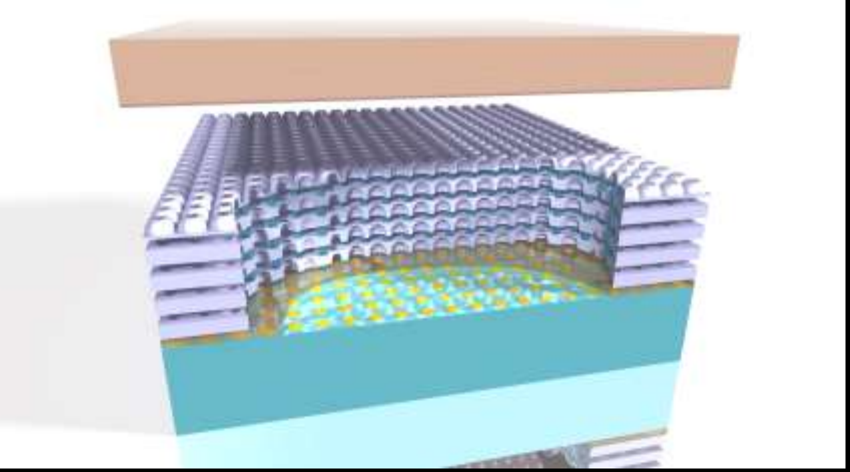
Interesting: - photo cathodes of PMs (bi-alkali etc)
- coating of dynodes of PMs
- Eff Alu, Cu: ~ 4 %
- Eff ceramics (Diamond, CsI, Si_3N_4): 10 - 20 %?

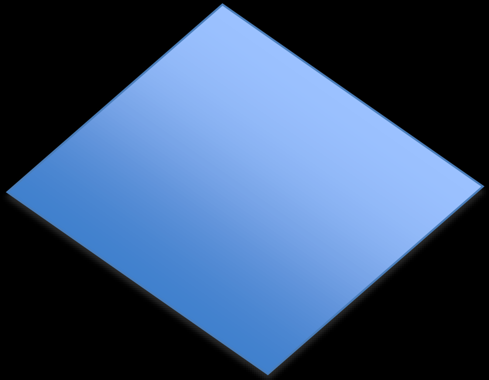
Extracting electric field (close to cold electron emission)

- nano grass









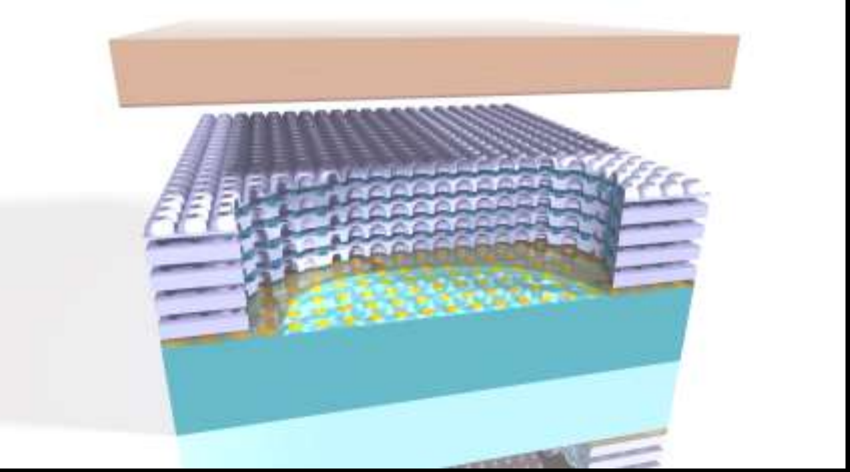
1” x 1”, 2 mm thick

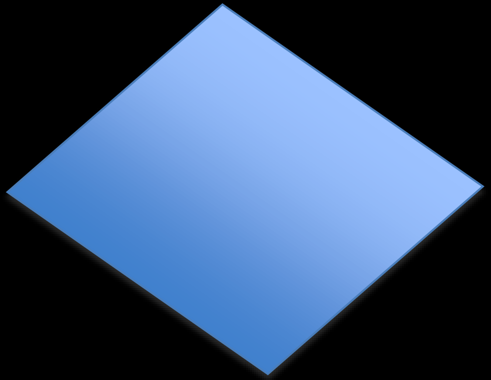
Timed Photon Counter TiPC Tipsy

- good (single) quantum efficiency
- ultra fast, ps time resolution
- low noise
- little dark current, no bias current
- radiation hard
- perfectly linear (high granularity)

- flat, thin & light
- 2D position resolution ~ 10 µm
- potentially cheap……!
- little radioactive
- can stand B fields

Potentially outperforms APDs, G-APDs, SPADs, dSiPMs, QUPIDs
Consumer application: 3D pictures by measurement Time-of-Flight…….!





1” x 1”, 500 μm thick

MIP Tracking detector Trixy

- moderate track efficiency 50 – 90 %
- ultra fast, ps time resolution
- low noise
- little dark current, no bias current
- radiation hard

- flat, thin & light
- 2D position resolution ~ 10 μm
- potentially cheap……!
- can stand B fields
- no 3D track vector info (GridPix)

Outperforms Si trackers in terms of time resolution
- high rate experiments
- BX timing: ILC/CLIC experiments