A new solid state tracking detector: Electron Emission Membranes and a MEMS made vacuum electron multiplier

only ideas: no data

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A very successful photon detector: the Photomultiplier (1948)

- good quantum efficiency
- rather fast
- low noise
- little dark current, no bias current
- radiation hard
- quite linear

- voluminous & heavy
- no position resolution
- expensive
- quite radioactive
- can’t stand B fields
Reduce size of dynodes (volume downscaling):

- keep potentials as they were ($V_{\text{step}} \sim 200 \, \text{V}$)
- (non relativistic) electron trajectories same form, but smaller (volume)
- multiplication yield: identical
- 1$^{\text{st}}$ dynode: focusing, yield
- pixel input source capacity: only $\sim 10 \, \text{fF}$
- required gain $\sim 1000 = 2.5^4 = 5$ dynodes sufficient

Apply MEMS Technology

[Diagram of a photomultiplier tube]

VACUUM!
No ‘gas amplification’
Use a MicroChannelPlate MCP?

John Vallerga: TimePix + MCPs

We do not know how to make MEMS made MCP. Problem: aspect ratio of holes

Quantum Limited Imaging Detectors, RIT 2009, John Vallerga, jvv@ssl.berkeley.edu
The transmission dynode: ultra thin (20 - 100 nm) layers

- Diamond
- SiNitride (Si₃N₄) Si doped (SiRichNitride, SRN)
- CsI
- doped SiO₂

- Ultra fast (single electron) detector: σ = 10 ps
- E-force much larger than Lorenz force: operates in B-field
- Radiation hard
- Low mass
Silicon Nitride

Thickness 15 nm!
50 μm SiNitride (Si-doped) (insulating) SiO₂
GridPix Gaseous Detector: a readout of Time Projection Chambers
The MediPix2 pixel CMOS chip

256 x 256 pixels
pixel: 55 x 55 μm²
per pixel:  - preamp
  - shaper
  - 2 discr.
  - Thresh. DAQ
  - 14 bit counter
  - enable counting
  - stop counting
  - readout image frame
  - reset

We apply the ‘naked’ MediPix2 chip without X-ray convertor!
Wafer post-processing: InGrid

InGrid: an Integrated Grid on Si (wafers or chips)

- perfect alignment of grid holes and pixel pads
- small pillars Ø, hidden pillars, full pixel area coverage
- Sub-micron precision: homogeneity
- Monolithic readout device: integrated electron amplifier
Full post-processing of a TimePix

- Timepix chip + SiProt + Ingrid:

- MESA+

- IMT Neuchatel

- Charge mode
$^{90}$Sr $\beta$ events

Gas: Ar/i-butane 80/20

Efficiency to detect single electrons $> 95\%$
Development of MEMS technology
Wafer Post Processing
‘There is plenty of room at the top’ supported by Dutch Economical Affairs
QuintGrid may be realized earlier

Development // Transmission Dynodes
We can make TripleGrids!
Photosensitive GridPix

Univ. Twente and Weizmann institute
InGrid with CsI on alu. anode
Detect by means of gasgain
Better anode readout \(\rightarrow\) TimePix

UV light 200-400 nm
First test, InGrid without CsI
UV well absorbed by my fingerprint

- photon
- transfer of primary \(e^-\)
- mesh cathode
- InGrid (Al) coated with 200 nm CsI
Reinforcement bars required: creates dead regions

Problematic for 1st transmission dynode
For tracking of fast charged particles (MIPS):

Replace photocathode by **Electron Emission Membrane**

Electron emission membrane

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

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
Possible improvements in electron emission efficiency:

- low work function (CsI, bi-alkali, CVDiamond)
- surface treatment: CVDiamond, nanotubes, fractals
- Extracting electric field

Try to develop membrane with 50 – 95 % efficiency!
Skin effect: only skin of ~ 50 nm participates in EE.
Rise of EE efficiency by surface enlargement: meandering, modulating, roughening

2\textsuperscript{nd} order modulation, 3\textsuperscript{rd} order… fractals!
Extracting E-field: constant at surface
Work function

Interesting: - photo cathodes of PMs (bi-alkali etc)
- coating of dynodes of PMs
- Eff Alu, Cu: ~ 4 %
- Eff ceramics (Diamond, CsI, Si$_3$N$_4$): 10 - 20 %?

Extracting electric field (close to cold electron emission)

- nano grass
Conclusions

MultiPix
MEMS made vacuum electron multiplier integrated on pixel chip

MultiPix + ‘classical’ photo cathode
Timed Photon Counter TiPC Tipsy

MultiPix + Electron Emission Membrane
MIP tracking detector
Timed Photon Counter TiPC **Tipsy**

- good quantum efficiency
- ultra fast, ps time resolution
- low noise
- little dark current, no bias current
- radiation hard
- perfect linear

- 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………!
MIP Tracking detector

- 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