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Collaborations:
Sincrotrone Trieste ELETTRA
University College London
Position-sensing with classical **Silicon Drift Detectors**

**ALICE**

- 256 anodes
- Wafer: 5”, (NTD) silicon, 3 kΩ·cm resistivity, 300 µm thickness
- Active area: 7.02 × 7.53 cm²
- \( \Delta x, \Delta y \approx 30 \mu m \)

**NA45/WA48**

- 360 anodes
- Wafer: 4” silicon, 300 µm thickness
- Active area: 55 cm² (4.2 cm radius)
- \( \Delta r = 44 \mu m \)
- \( \Delta \Phi = 2.6 \text{ mrad} \)

...but...

- **START TRIGGER NEEDED**!
- no imaging of random sources (x/γ/…)

- **FREE LATERAL BROADENING**!
  - doping inhomogeneities
  - limited spectroscopic performance
  - reduction of the event rate

~5 Mpixel with ~500 output channels!
The Controlled Drift Detector* (CDD)

Novel features
- potential minimum near top surface
- suppressed lateral broadening
- control of drift field: “integrate-readout” mode
- integrated front-end JFET: high energy/position resol.
- fast timing signal from back electrodes

- electron packets are drifted at high speed (0.5-1.5 cm/µs) towards point-like anodes (<100 fF)
  - deposited energy is obtained from the electron charge (Q)
  - interaction position along the drift is obtained from the drift time (T_d)
  - interaction position along 2nd coordinate is obtained by anode segmentation

⇒ fast readout, position sensing/reduced no. of channels and spectroscopy of radiation


(*) INFN-MPI Patents:
US 6,249,033
EP0862226
CDD working principle: simulation @ z=12 µm

Integration phase:
Signal electrons are collected in suitably engineered potential wells

Readout phase:
A uniform drift field transports the electrons to the readout anodes in few µs.

Operating modes:
• integrate-readout mode
• free-running mode (self-trig, XFEL)

$T_{\text{drift}} = 1-2 \mu s/\text{cm}$
\textbf{Controlled-Drift Detector - Layout and photo}

A.Castoldi, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, NIM A512, October 2003

- **0.3 cm$^2$ active area** - pixel 120\(\mu\)m/180\(\mu\)m
- **Back side**
  - 8 strips (900\(\mu\)m)
- **Active area**
  - 30\(\times\)34 pixels
  - (180\(\mu\)m side)
- **Read-out**
  - 30 channels
  - on-chip JFET
- **6.1 mm drift length**

High energy implantation (20 MeV) instead of grown epitaxy \(\Rightarrow\) drift channel is located at about 7\(\mu\)m from the implanted surface

- **Detail of anode region with integrated front-end JFETs**

- **Mounted 6x6 mm$^2$ prototype**

**Design and Testing**

- Designed, layouted and tested at Politecnico di Milano-INFN, Italy
- Produced at the Halbleiterlabor of the Max Planck Institut, Munich (D)

Andrea.Castoldi, PoliMI & INFN
1-D imaging and spectroscopy of a Fe-55 source @ 100 kHz


Δt = 55 ns

FWHM = 11 ns

integration

readout

9 µs

1 µs

Frame frequency = 100 kHz

Pixel 180µm x 180µm

270 eV FWHM @ 300K @ 0.25 µs
(28.6 el. r.m.s.)

198 eV FWHM @ 223K @ 0.5 µs
(18.7 el. r.m.s.)

DRIFT TIME [µs] ÷ X

ENERGY [eV]

counts

0.0 0.1 0.2 0.3 0.4 0.5 0.6

5E+3 1E+4

Andrea Castoldi, PoliMI & INFN
55Fe radioactive source
$E_{\text{drift}} = 300\text{V/cm}$
$\Delta V = 2\text{V}$
$T = 300\text{K}$

- Frame frequency = 10kHz: 837 eV FWHM
- Frame frequency = 30kHz: 339 eV FWHM
- Frame frequency = 80kHz: 290 eV FWHM
“Electronic” collimation


$^{55}$Fe radioactive source

- $f_{\text{frame}} = 100\text{kHz}$
- $E_{\text{drift}} = 300\text{V/cm}$
- $\Delta V = 2\text{V}$
- $T = 300\text{K}$

$\tau_{\text{sh}} = 250\text{ ns}$

All data charge sharing events rejected

(Charge sharing events) + (first and last pixel) rejected

Andrea. Castoldi, PoliMi & INFN
2-D spectroscopic imaging of X-rays with CDDs

Radiographic image of a lizard*...

... and spectroscopic analysis of each pixel

* no animal was killed or suffered for this measurement

Andrea Castoldi, PoliMI & INFN
2D/3D tomographic imaging at 100 kHz frame rate

Pixel 120 μm, 28 keV x-rays (0.44 Å), 10⁵ frame/s, T=300K

Digital radiography of a wisdom tooth

2D projections of a tooth section of 1.7 mm

3D reconstruction
2D Elemental mapping by K-edge subtraction imaging

The distribution of a known element (i.e. silver) in the sample is obtained by imaging the sample in two X-ray windows, one below and the other above the K-edge of silver, and looking at the image difference.

The spectroscopic capability of the CDD allows mapping of principal elements in the sample with ~100µm position resolution from a single image acquisition (i.e. multiple-energy technique)

Exp. CODERA - Gr. V - INFN Sez. Milano
Diffraction Enhanced Breast Imaging (DEBI)

Scattered intensity vs. momentum transfer
-> LAXS signature for tissue/material analysis

$\chi = \sin(\theta/2)/\lambda$

Exp. set-up at fixed angle (9°)
mechanical collimator Ø0.5mm

Sincrotrone Trieste (SYRMEP)

Royle, Speller (1999)
Experimental results on tissue: contrast and specificity

Transmission images:
(pixel 120um)

Contrast = 27%

Contrast = 12%

Diffraction images:
(pixel 500um)

Contrast = 48%

Contrast = 32%

E = 18 keV

\( \chi / E \)

E = 26 keV

\( \chi / E \)
Time-resolved X-ray imaging of repetitive processes

Experimental setup:

- CDD operated at 100 kHz
- Drift field 400 V/cm, T=300 K
- Input signal: 219 Hz sine wave
- Mask displacement: 2.3 mm p-p

Acquired time-sliced X-ray images

(integrate-readout, 100 kHz)

1 µs resolution in free-running mode

⇒ pump-and-probe techniques
Electron tracking of the first Compton scatter can significantly increase sensitivity of Compton telescopes:

Approximate determination of dE/dx from experimental data:

- direction of recoil electron
- data fitting: recoil electron energy, deposited energy, escape energy
- analysis of back signals may provide Depth-Of-Interaction information
Andrea Castoldi, PoliMI & INFN

$T_{\text{electron}} = 959.8 \text{ keV}$

$\sigma = 0.028 \text{ keV/\mu m rms}$

$E_{\text{out}} = 758 \text{ keV}$

Electron tracks

Na-22 source, $T = 300\text{K}$

Z-exit

internal absorption
2D imager based on $3\times1$ cm$^2$ CDDs
(project#1: x-ray imaging, project#2: Compton scatter detector)

HV region

Pixel size (120µm) and readout section

240 x 84 pixels

width 28.8 mm
drift length 10.2 mm

P-side: 15 strips (pitch 780µm)

Scientific collaboration with MPI Munich for technology development/detector production (2005)

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Preliminary tests with Am-241 (march ’06)

T=300K
E_{\text{drift}}=400 \text{ V/cm}
T_{\text{drift}}=2.3 \mu \text{s}
67 \text{ kframes/s}
t_{\text{sh}}=0.1 \mu \text{s}

FWHM = 7.5 \text{ ns}

\Delta t = 29 \text{ ns}

530 \text{ eV fwhm (59 el. rms)}

13.9 \text{ keV}
20.7 \text{ keV}
26.2 \text{ keV}

Energy [keV]

Pixel

Energy [keV]

Pixel