Medical X-Ray Imaging with Energy Windowing

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Overview

- Overview of the MPEC chip family
  - Assemblies with Si- and GaAs sensors

- The MPEC 2.1 chip
  - Energy windowing
  - Performance
  - Sensors

- Conclusion and outlook
Overview of the MPEC Chip Family

- **Multi Picture Element Counters**
- **First chips (MPEC 1.0, 1.1) derived from ATLAS Pixelchip Prototype**
  (Bier & Pastis, Phys. Inst. Uni Bonn, CPPM Marseille)

**MPEC 1.0**
- 12 x 63 pixel
- 50 µ x 433 µ
- 15 bit shift counter

**MPEC 1.1**
- Minor bugfix to MPEC 1.0
- Bump bonded to Si and GaAs sensors

**MPEC 2.0**
- 32 x 32 pixel
- 200 µ x 200 µ
- 18 bit shift counter

**MPEC 1D**
- Energy windowing
- 2x 15 bit shift counter

**MPEC 2.1**
- Energy windowing
- 32 x 32 pixel
- 200 µ x 200 µ
- 2x 18 bit shift counter
Sensor Assembly (1)

- Solder bump bonding
  - Used for ATLAS pixel modules
  - Fine pitch (50 μ) possible
  - Solderwettable under bump metallization requires processing of whole wafers

- MPEC 1.1 assembled with
  - Si sensors
  - GaAs sensors

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Pixel 2000, Genua 8.6.00
Imaging Resolution

Radiogram of a small slit to determine the Line spread function LSF

Single chip assembly with MPEC 1.1 and bump bonded Si sensor

- **NEP ≈ 9.5 lp/mm** (noise equivalent pass band, MTF = 0.3) in direction of 50 µ pixel edge
Synchrotron Beam Measurements

Test setup at European Synchrotron Radiation Facility (ESFR)
(in collaboration with the Paul Scherrer Institute, PSI)

- Inhomogeneity < 2%

![Inhomogeneity Graph]

- Efficiency

![Efficiency Graph]

Scan with collimated beam
Performance of Si and GaAs Sensor

- **Si Sensor**
- **GaAs Sensor**

- Count rate improves by a factor 10 for GaAs (60 keV $\gamma$)
- GaAs sensors show inhomogeneous efficiency
MPEC 2.1 Architecture

- 0.8 μ CMOS active area 6.4 mm x 6.4 mm
- 32 x 32 pixel, size 200 μ x 200 μ
- Preamp, two discriminators and two counters in each pixel
- Serial readout for four columns each
Energy Windowing

- Absorption for different tissues is energy dependent
- Contrast enhancement with energy window

Transmission spectrum with energy window
Contrast between two different tissues
MPEC 2.1 Pixel Schematic

[Diagram of pixel schematic with labels for components such as Bump pad, VTH1, VTH2, VCCD1, VCCD2, ENABLE1, ENABLE2, EXTCELL, MODE1, MODE2, PREV COUNTER, NEXT COUNTER, and INJECT.]
Pixel Layout
Preamplifier

- Charge sensitive preamplifier
  - Design adopted from ATLAS prototype chip Bier & Pastis
  - Current feedback
  - No additional shaper
  - Return to baseline \( \approx 500 \text{ ns} \)

Analog out for different feedback currents (a), and different signal charges (b), (Rise time limited by output-buffer)
Counter

- 18 bit LFSR counter
- FF with 6 transistors
- Max. clock frequency > 10Mhz
- Dynamic logic, refresh needed (low frequency, < 1Hz)

18 bit linear feedback shift register counter

Single phase Flip Flop

Counter tests with different refresh delays
Window Logic

- Window discriminator
- Count signals above upper threshold only in upper counter
- Increase dynamic range
- Decrease crosstalk between counters and preamplifier

Threshold scan shows the sum of both counters is 100 % (no loss)
Noise Performance

- **Average equivalent noise charge is 42 electrons** (measured with upper discriminator)
- **Upper discriminator shows slightly higher noise (74 electrons)**
Threshold Dispersion

- **Window discriminator demands low threshold dispersion**

- **Thresholds dispersion < 13 electrons with adjust**
Threshold Adjust

- Global threshold and individual correction voltage for each discriminator

- Correction voltage stored on a capacitor

- Ultra low leakage of drift compensation (0.03 fA)

- Threshold drift only 0.2 electrons per second

- Refresh during normal exposure times not necessary

Drift compensation with buffer and double switch

Drift of the stored compensation voltages
Sensor Assembly (2)

- **Gold stud bump bonding**
  - Mechanical process
  - Assembly of single chips

- **Sensors for MPEC 2.1**
  - Si (successful assembled, chip failure)
  - GaAs (assembly failure, sensor met.)
  - CdTe (sensor available)

Mechanical gold stud bumping (IZM, Berlin)

MPEC 2.1 with gold studs

Metallization of the GaAs sensor

CdTe sensor bonded with gold studs to a dummy chip
Conclusion

- First MPEC counting pixel chips derived from ATLAS electronics
- Chip assembly with Si and GaAs sensors
- Features individual threshold adjust and energy windowing

Outlook
- Assembly MPEC 2.1 with Si, GaAs and CdTe sensors
- Next MPEC generation in deep-submicron technology

Papers and additional information: http://xray.physik.uni-bonn.de/