KETEK

Latest Developments in KETEK’s Silicon Photomultiplier Solutions

Tobias Eggert, Wolfgang Gebauer, Florian Wiest
• Family-owned enterprise, founded in 1989 by Dr. Josef Kemmer

• 100 employees. Headquarter: Munich, Germany

• Major product lines:
  
  - SDD modules, detector electronics and complete systems

  - **Silicon Photomultipliers (SiPM)**

• Quality Management certified according to ISO 9001:2015
SiPM Working Principle

Histogram of the response to a pulsed laser source

- Quenching Resistor
- Antireflective layer
- Bias
- Avalanche zone
- N-doped body
- P-doped entrance window

V-High

V-Low

Current Density $j$ $[A/cm^2]$

Bias Voltage $[V]$

Geiger Modus - APD

Break Down

Working Point

ON

OFF
SiPM Applications

Communications
-矿业
-回收
-光学测量
-通信
-激光雷达
-单光子计数
-光致发光光谱学（OES）

Optical Measurements
-流式细胞术
-二光子显微镜
-寿命光谱学
-细菌检测
-DNA分析
-氧气测量

High Energy and Astro Physics
-正电子发射断层扫描（PET）
-单光子发射计算机断层扫描（SPECT）
-伽马相机
-荧光诊断
- calorimetry
-触发和 veto detectors
-切尔诺夫望远镜
- Astro-Particle Physics

Biotechnology, Life Science
-遗传学
-生物医学
-生物医学

Homeland Security
-行李和货物扫描
-环境监控
-危险威胁检测

Medical
-光学
- gamma 相机
- Fluorescence Diagnostics

Tobias Eggert
4 July 2019
KETEK - iWoRiD 2019
KETEK SiPM WB-Series

Photo detection efficiency of the WB Series SiPMs versus photon wavelength. The peak PDE is at ca. 430 nm.

**Excellent PDE to cell size ratio.**

\[ PDE(\lambda, V) = QE(\lambda) \cdot \varepsilon(V) \cdot GE \]

- \(QE\): Quantum Efficiency
- \(\varepsilon\): Geiger/Breakdown Efficiency
- \(GE\): Geometrical Efficiency (active area)
- \(\lambda\): Wavelength
- \(V\): Bias

PM3325: 43 % @ 430 nm

Typical Dark Count Rate (DCR) of the WB Series versus overvoltage.

**DCR greatly improved**

- Dark pulses = pulses not being excited by incoming light
- Dark pulses are triggered by thermally generated electrons
Dynamic Range of SiPM

- The dynamic range is limited by the recovery time and the number of micropixels
- PM3315-WB
  - Recovery Time: 13ns
  - Number of pixels: 39k

\[ N_{\text{Pixel-fired}} = N_{\text{Cell}} \cdot \left(1 - e^{-\frac{\text{PDE} \cdot N_{\text{Ph}}}{N_{\text{Cell}}}}\right) \]

- \( N_{\text{Pixel-fired}} \): Number of fired Cells
- \( N_{\text{Cell}} \): Total Number of Cells
- PDE: Photon Detection Area
- \( N_{\text{Ph}} \): Number of incident Photons
KETEK WB Series: Reliable and Cost Efficient

Wafer Level Package
- Cost efficient
- High volume production
- Robust and reliable
- Insensitive to high magnetic fields

PM11
- 1x1 mm² active area
- 1.315 x 1.315mm² lateral size
- Ideal for high resolution arrays

PM33
- High shearing forces (~30N/device)
- Excellent package fill factor

Tape and Reel Delivery
WB Series - Reliability Test Procedure

<table>
<thead>
<tr>
<th>Test</th>
<th>JEDEC Test Method</th>
<th>Test Conditions</th>
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| PC     | Pre-conditioning / MSL classification according to J-STD-020 | MSL1: Moisture Sensitivity Level 1  
- Temp.-Cycle: 5 x -40°C / +60°C  
- Bake: 24h at 125°C  
- Soak: 168h at 85°C / 85% R.H.  
- Reflow: 3 x Peak 255°C – 260°C |
| TC     | Temperature Cycling according to JESD22-A104            | 1000 cycles @ -55°C/125°C without bias               |
| H³TS   | High Humidity High Temperature Storage according to JESD22-A101 | 1000h @ 85°C/85% RH without bias                     |
| HTS    | High Temperature Storage according to JESD22-A103      | 1000h @ 125°C without bias                           |

- 45 devices of each batch are picked for reliability testing
- 10 devices for ESD test (3kV HBM)
- Additional reliability tests with applied bias voltage have been successfully completed (HTRB + H³TRB)

**Reliability Testing**
- MSL1: 45pcs
- TC: 15pcs
- H³TS: 15pcs
- HTS: 15pcs

**Moisture sensitivity level**
J-STD-020: Components must be mounted and reflowed within
- MSL 3 – 168 hours
- MSL 2 – 1 year
- MSL 1 – Unlimited
“floor life out of the bag”
SiPM Arrays off the shelf

PA33xx-WB-0808
64 channel array with 80% fill factor

New PA1125-WB-0808
High resolution SiPM array

PA3325-WB-0404
16 channel array with 80% fill factor
Custom SiPM solutions

Custom arrays based on SiPM WB series

SiPM module with integrated cooling in TO8 housing

4x PM3325-WB on evaluation PCB for optical bench applications
Customized SiPM Chips

Monolithic 64-channel-array for the University of Tokyo

Linear 64-channel SiPM chip for CERN LHCb experiment

Round-shaped high dynamic range SiPM for CERN CMS

- 64x0.16mm² active area
- 64x400 cells / 20µm pitch

- 8.6mm² active area
- 38158 cells / 15µm pitch
SiPM Module successfully tested and evaluated at MoFlo (Beckman Coulter cell sorter)

- PM3315-WB SiPM based
- Integrated Transimpedance Amplifier (TIA)
- Plug and Play Solution for Cytometry
- Control Input for SiPM Bias Voltage

- Compatible with Thorlabs® SM05 Optics and Hamamatsu® PMT mounts
- TIA Module output signal directly can be fed into DAQ without further preprocessing
- Highly cost effective solution compared to PMT

Energy [a.u.]

Count

Data courtesy of Dr. Malte Paulsen (EMBL, Heidelberg)
Conclusion

• KETEK SiPM combine high fill factor with large dynamic range
• Highly reliable and robust chip-size package
• Customized as well as off-the-shelf array solutions
• Customized electronics and cooled SiPM modules
• Flexible partner for industrial and scientific projects
30 YEARS 1989 - 2019
THANK YOU

CREATIVE DETECTOR SOLUTIONS

SDD
THE GOLD STANDARD IN SILICON DRIFT DETECTORS

SiPM
SILICON PHOTOMULTIPLIERS NEXT GENERATION VERSATILITY
Backup
Silicon drift detectors for X-Rays

- KETEK’s VITUS Silicon Drift Detectors (SDD) are the state-of-the-art X-ray detectors for 0.05 keV - 50 keV energy range
- Applications such as EDS, XRF, μXRF and TXRF
- Patented graphene window
- Tailored electronics solutions for unprecedented performance
- Modern production facilities in Munich
- VITUS SDD on Mars rovers „Spirit“, „Opportunity“, „Curiosity“ and on NASA/JPL PIXL experiment for „Mars 2020“ rover
• First Certification according ISO 9001:2015 in April 2017
• Successful Re-Certification according ISO 9001:2015 in March 2018
• Quality Policy

Quality is the basis of all activities at KETEK, and every employee contributes significantly to quality.

It is our ultimate goal to gain and maintain satisfied and convinced customers. This is achieved through in-time and precise products and services and by competent and friendly cooperation with our customer's staff. These goals require commitment, expertise, and personal responsibility of all employees.

The production of the detector and electronics systems is monitored by methods of statistical process control and optimized for quality and cost. Highest yield, on-time delivery, and a zero-defect quality are the objectives of all processes, products, and services. Moreover, they are essential to ensure the company's future.

Close cooperation with key customers allows KETEK an on-time development and production of customized detector solutions with a high value creation. This leads to close customer loyalty and ensures the quality characteristics of KETEK’s products and systems in the market.

Full commitment to quality during their work and active contribution to the continuous improvement to the quality of KETEK’s products, processes, and services are expected from every employee in order to improve the quality continually.
Typical Dark Count Rate (DCR) over Temperature
DCR greatly improved
Flow Cytometry with KETEK SiPM TIA Module

- Comparison of PMT vs. SiPM TIA Module – 8 peaks Rainbow Calibration Particle

setup parameters: 488nm 200mW laser power 530-40

Data courtesy of Dr. Malte Paulsen (EMBL, Heidelberg)
PET: Medical Imaging for Cancer Diagnostics

SiPM is the ideal detector

Demand for high SiPM volumes

[2] gehealthcare.com
Multichannel Readout of Block Detector

• 5 x 5 SiPM array with 25 pcs PM6660 (6 x 6 mm² active area, 60 µm cell size)
  • 15 x 15 LYSO crystal array, each crystal 1.5 x 1.5 x 10 mm³, pitch 1.55 mm, 3M ESR reflector, Saint Gobain BC 630 optical grease, light guide 2.7 mm

• Read out by Multichannel Readout System
Waste Sorting Application – First Prototypes

- Line Array Prototype with 32 PM3350 and GAGG scintillators
  - Read out by PETsys Electronics
Environmental Surveillance: Fukushima

- **Compton Camera** with our SiPMs (PM66)
- Radiation Monitoring and Surveillance

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Kenji Shimazoe
http://dx.doi.org/10.1080/00223131.2015.1089796
X-Ray Transmission Spectroscopy
XRF-Measurement with SiPM + Scintillator

- PM1150-EB with 1.2x1.2x4 mm³ LYSO
- 50 keV X-Ray Source
- No Pre-amplification
- Charge Integration at 50 Ohm with Oscilloscope

ΔE/E~50-60% for all energies

X-Ray Spectroscopy with SiPM + LYSO

- Nd (~37 keV)
- Sn (~24.2 keV)
- Ag (~22 keV)
- Mo (~17 keV)
- Pb (~12 keV)
- Au (~10.7 keV)
X-Ray Counting – Radiation Monitoring

- **SiPM** in combination with a **scintillator** can be used for X-Ray counting
  - Limited energy resolution
  - Lower limit currently reached: 5.9 keV, \( \frac{dE}{E} = 50\% \text{ FWHM (3keV)} \)
  - Energy range of detection complimentary to SDD

KETEK PM6660 coupled to GAGG scintillator

Counting the interactions of Fe-55 (5.9 keV) 50% FWHM energy resolution
Single Photon Spectrum measured by use of a short pulsed laser (<100ps pulse width)
WB Series – PM33XX

- cost efficient
- high volume production
- robust & reliable
- MR compatible

Tape and Reel Delivery
NEW PM11XX-WB

- Smallest 1x1 mm² device
- Ideal for high resolution arrays

Side View

Active Area

Tape and Reel Delivery