The silicon photomultiplier

Stefan Gundacker and Arjan Heering

.

Parameters

Quality measures

error sources

Digital SIDM

Applications

Prospec

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SPAD: Principles of operation

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A P P

nd Arjan Heering ■ p-n diode

■ 3 regimes:

simple e-h creation through impact ionization

2 secondary ionization by e

3 secondary ionization by e and h (quenching needed)

e ionization is more sensitive

n-on-p for red

p-on-n for blue

electrical equivalent circuit of the SPAD

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breakdown voltage

$$\int_0^W \alpha_n e^{-\int_0^x (\alpha_n - \alpha_p) dx'} dx = 1$$

ullet V_{bd} is more advantageous for thin depletion regions

$$Gain = rac{avalanche_charge}{a} = rac{V_{ov}(C_q + C_d)}{a}$$

g gain gives signal well above noise for q = e

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- lacktriangle measuring the gain as a function of V_{bias} .
- find the derivative

temperature dependence of parameters

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- $lacktriangleq V_{bd}$ increases with T
- gain increases with lower T
- DCR increases with T

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Application

$$\textit{PDE}(\textit{V}_{\textit{ov}}, \lambda) = \textit{QE}(\lambda) \textit{P}_{\textit{T}}(\textit{V}_{\textit{ov}}, \lambda) \textit{FF}_{\textit{eff}}(\textit{V}_{\textit{ov}}, \lambda)$$

SPTR

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$$\sigma_{\textit{timing}} = \frac{\sigma_{\textit{v}_{\textit{voise}}}}{\textit{dv}/\textit{dt}_{\textit{@threshhold}}}$$

error sources

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DCR

- lacksquare $\propto rac{1}{T}$
- residue at cryo. temperature: trap assisted tunneling
- after pulse:
 - release of trapped charges in high field regions
 - mitigation: slow recharge rate
 - secondary photons
 - mitigation: low life time substrate

Crosstalk

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Applications

Prospec

- photons arising from one cell triggering a signal in an other cell
- Mitigation: optical trenches
- delay cross talk
- Mitigation: reduce undepleted region thickness
- external crosstalk: emission of secondary photons producing reflection on "the window"
- Delayed vs. prompt cross talk.

Excess noise factor

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Digital SiPN

Application

- lacksquare Expectation: $N_{phe} \pm \sqrt{N_{phe}}$
- we define

$$ENF = \frac{(\sigma_Q/< Q>)^2}{(\sigma_{Q_N}/< Q_N>)^2}$$

Saturation

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Application

rospect

trade of between saturation and dead space

$$N_{fired} = N_{total} \left(1 - e^{-rac{N_{photon}PDE \cdot ENF}{N_{total}}}
ight)$$

digital SiPM

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Digital SiPM

Application

- each cell has it's own read out
- high data production
- compromise: small SiPM arrays

Applications

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Digital SiPM

Applications

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- TOF-PET
- PET-MR
- SPECT/MR
- HEP
 - Problem: High radiation environment
- LIDAR
- Scintillation detection
 - Cherenkov in scintillator

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Application

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■ Digital will become more prevalent

Abbreviations

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Applications

Аррисаціона

Prospect

■ SiPM: Silicon photomultiplier

SSPM: solid state photmultiplier

MPPC: multi pixel photon counter

■ SPAD: single photon avalanche diode

■ SPTR: single photon time resolution

■ PDE: photon detector efficiency

PMT: photo multiplier tube

TCAD: technology computer aided design

DCR: dark count rate

■ LTE: light transfer efficiency

■ PTS: photon transfer time spread

Abstract

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Application

- What is SiPM and what is it use for
- What are relevant qualitative parameters for best application specific performance

introduction

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Applications

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Analog vs. Digital SiPM

■ $10 - 100 \mu m$ wide

single photon sensitivity

ps timing resolution

applications:

TOF-PET

101-11

LIDAR

dark matter

lacksquare double eta

HEP

much more

electronic read out

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Application:

- high gain
- high power consumption
- strong and fast amplifier

Analog SiPM

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Application

- large array of SPADS in parallel
- Counting photons via integration over charge
- individual SPADS interact via capacitance