Applications of photonic crystals to improve detector efficiency

Seminar of Low Energy Physics

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Overview

Introduction to Photonic Crystals

Principle of crystals

- periodic arrangement of atoms and molecules
- repeating pattern for atoms and molecules is crystal lattice
- = periodic potential to an propagating electron (lattice impacts conduction properties)
- optical equivalent: photonic crystal (periodic macroscopic media with different dielectric constants)

- light modes due to refractions and reflections of light from interfaces
- many different ways of propagation possible
- possible: photonic crystals with band gaps

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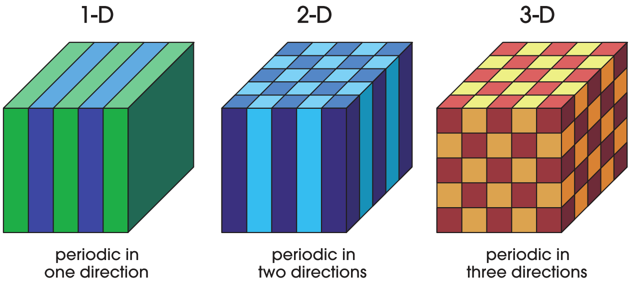
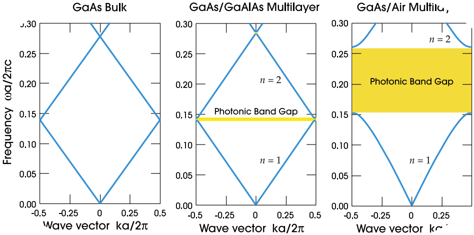


1-dimensional crystals

- simplest possible photonic crystal: a multilayer film.
- periodic in the z direction and homogeneous in the xy plane.
- use defects in order to localize light modes
- Dielectric difference between layers create a photonic band gap



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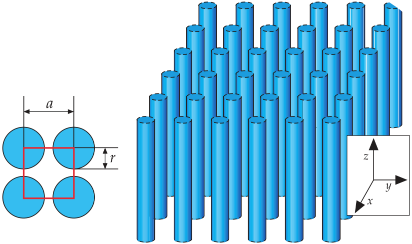
2-dimensional crystals

- periodic along two axes and homogeneous along the third axis
- photonic band gap in the xy plane depending on the column spacing



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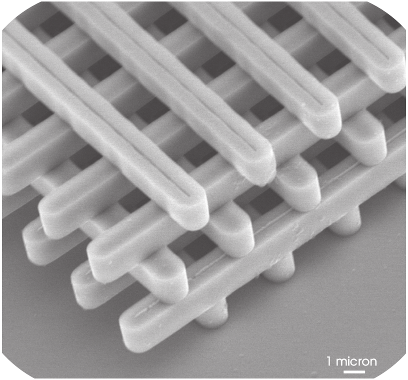
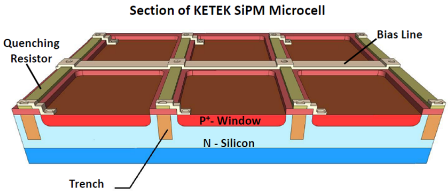
3-dimensional crystals

- analog to an ordinary crystal: dielectric structure periodic along three different axes
- possible properties as band gaps, defect modes and surface states



Introduction to Silicon Photomultiplier

- constructed of pixels made of Avalanche Photo Diodes (APD)
- quench resistor
- anti reflective coating and protection cover
- trenches against crosstalk
- guard rings around active decectiona area

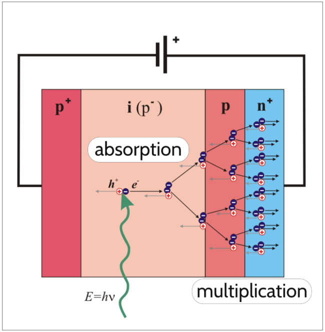


Ketek. https://www.appec.org/wp-content/uploads/Images/News-images/FigSergey1-1.png

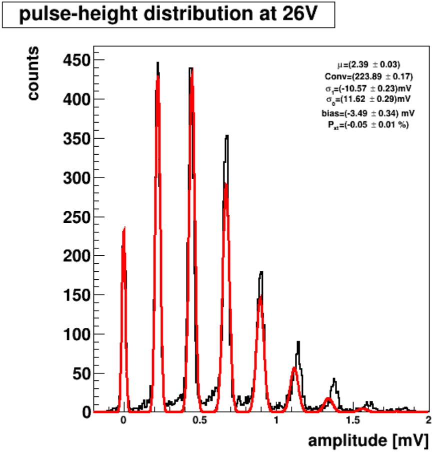
Avalanche Photo Diode

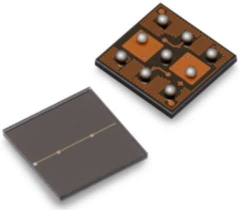
- simple photo-diode: n-doped semi conductor with a p-doped semi conductor (pn-transition)
- avalanche photo-diode: additional p-doped layer between i-layer and n^+-layer

- photon absorbed in p-layer or i-layer
- strong electric field between p^+ and n^+
- due to ionisation the accelerated electron produces more electro-hole pairs
- the original signal is amplified a lot (avalanche)



https://upload.wikimedia.org/wikipedia/commons/3/3a/APD3_German.png





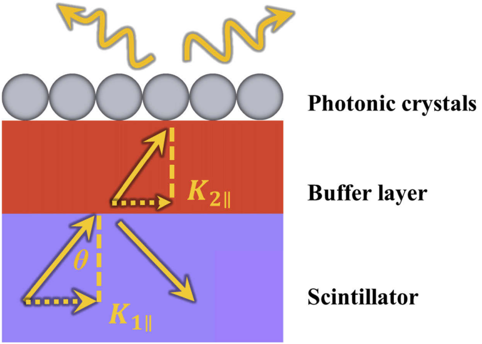
https://www.broadcom.com/products/optical-sensors/silicon-photomultiplier-sipm/afbr-s4n33c013

- single photoelectron (p.e.) resolution in spectrum
- size of 1 p.e. important to identify pulses

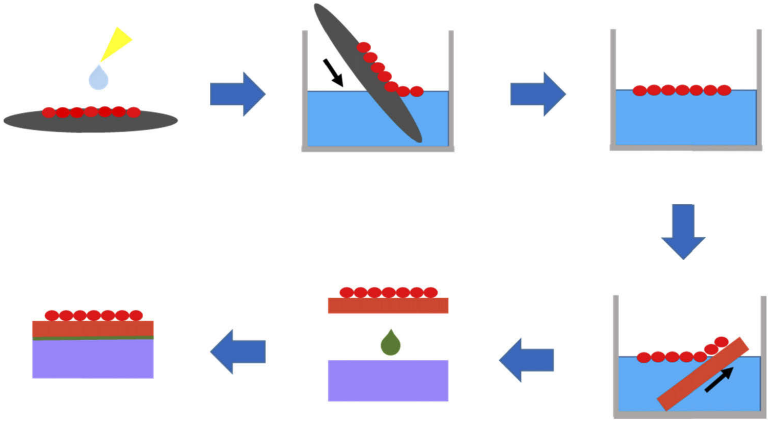
Application of photonic crystals to improve SiPMs

Buffer layers in scintillators

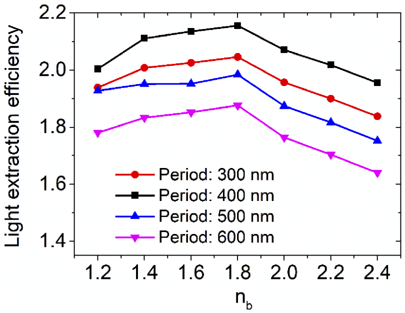
- SiPMs are often used in combination with scintillators
- low light-extraction efficiency of scintillators due to total internal reflection → use of photonic crystals fabricated on scintillator
- sometimes photonic crystals cannot be fabricated directly on the scintillator



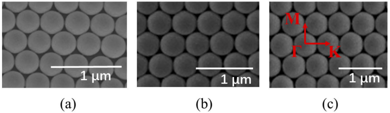
Convenient method for improving the light output of scintillators by using buffer layers coated with photonic crystals - Zhichao Zhu et al. - page 3



Convenient method for improving the light output of scintillators by using buffer layers coated with photonic crystals - Zhichao Zhu et al. - page 2



Convenient method for improving the light output of scintillators by using buffer layers coated with photonic crystals - Zhichao Zhu et al. - page 5



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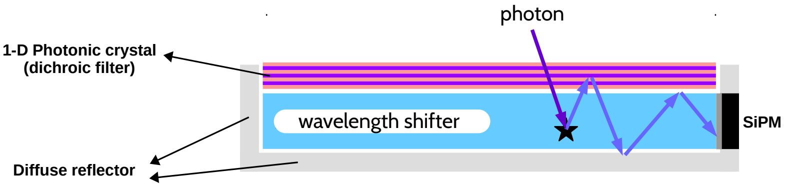
- difference between refractive index n_b of buffer layer and n_s of scintillator strong impact on coupling efficiency
- Photonic crystals (PC) with different periods, best result for PC with similar wavelength as scintillation light

Photo-Trap

- SiPMs have an small active area
- How make large pixels made of SiPMs?
- Photo-trap: Combination of SiPM, wavelength shifter and photonic crystal (dichroic filter)



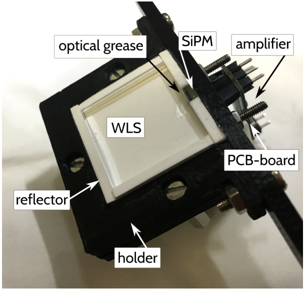
Seminar - Photo-trap - a low cost solution for a large-area, low-noise SiPM pixel - Daniel Guberman

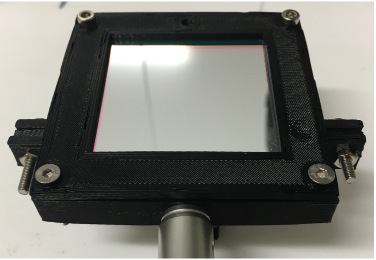
Advantages

- single photon resolution
- time resolution of SiPM
- large active area
- PC and WLS can be adapted for applications (surrounding material)
- cheap

Disadvantegs

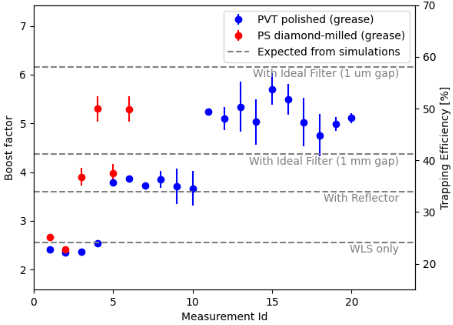
- low efficiency

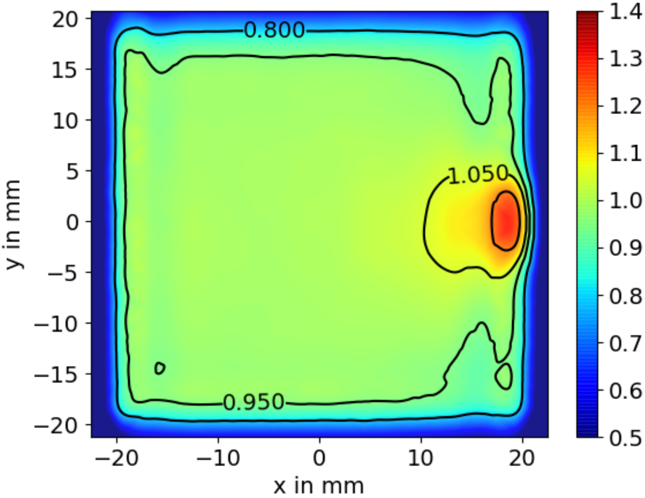




Seminar - Photo-trap - a low cost solution for a large-area, low-noise SiPM pixel - Daniel Guberman

- from simulations: higher detection efficiency with PC compared to pixel without PC
- measurements in the laboratory showed same effect (around 20% improvement) - preliminary

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