Study of detection efficiency distribution of SiPMs and SiMPI prototypes at the MPI HLL

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Outline

1. Test setup overview
2. Measurements & Results
3. SiMPI device
4. Summary & Conclusions

Areal sensitivity characterization test setup

Is useful for:

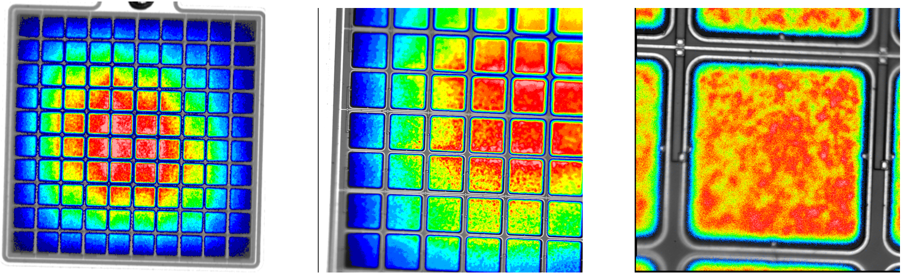
- studying of SiPM detection efficiency uniformity
- design optimization for development of new photon detectors
- comparing different commercial and non-commercial sensors
- studying of properties of different design
- getting precise information of shape of active area
- determination of geometrical fill-factor

Goal of our study

Ultimate goal

Discovering of sensitivity distribution of a SiPM over its area

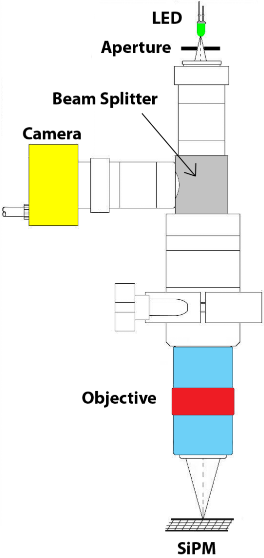
- separating signal from dark count and leakage current
- photon emission measurement in not capable of providing that information
- small light spot size allows us to perform such scan even within a single microcell



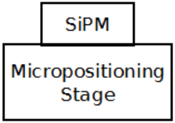
Photoemission images

Basic idea of the setup

- light from an LED is focused to a small point ($\phi \sim 1$ μm)
- focus and sensor allignment are corrected on chip surface orientation
- the LED is pulsed (10 ns long pulses, 10 000 - 65535 shots per step)
- SiPM response is measured in coincidence with LED pulses
- the light beam is driven through any part a SiPM matrix in discrete steps (≥ 1 μm)
- a sensitivity scan of a 1×1 mm^2 device with 1 μm step size can be completed in < 40 hours



Block scheme



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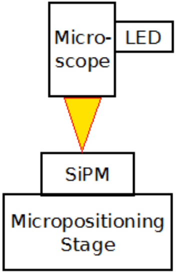

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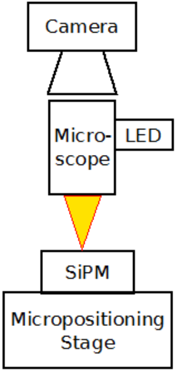

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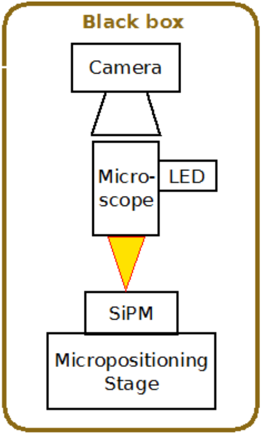

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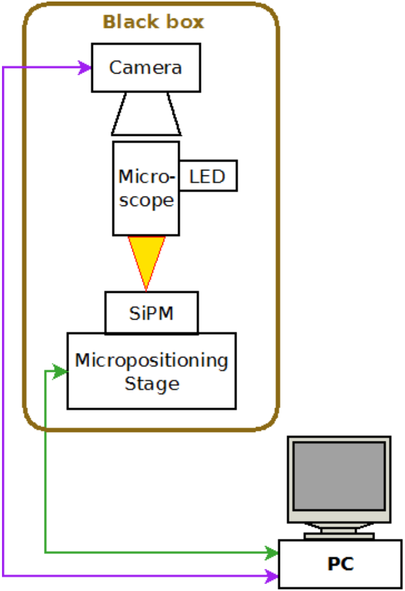

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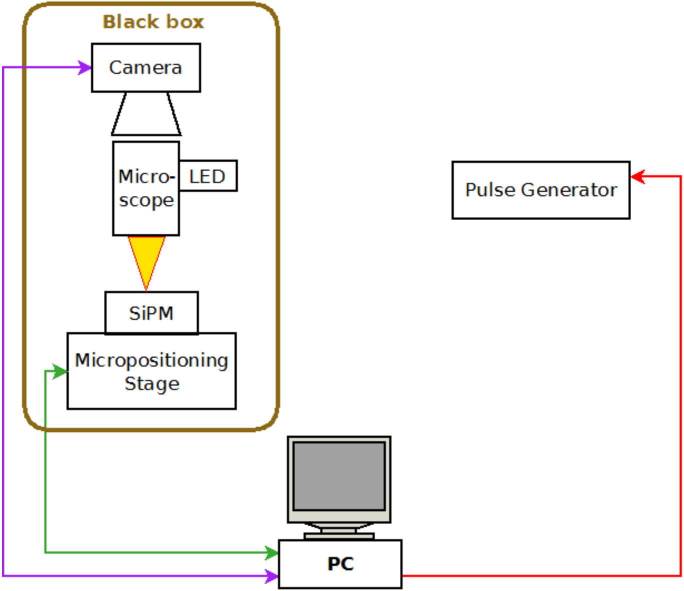


Black box

Camera

Micro-scope

LED

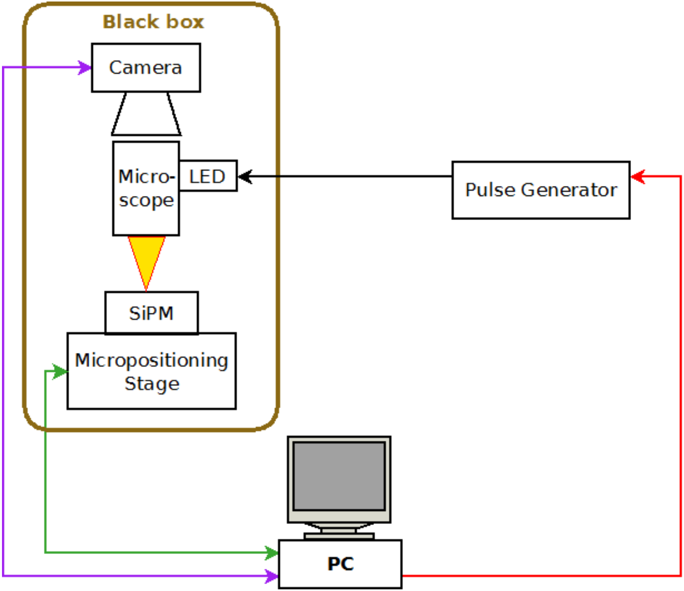
SiPM

Micropositioning Stage

Pulse Generator

PC

Block scheme



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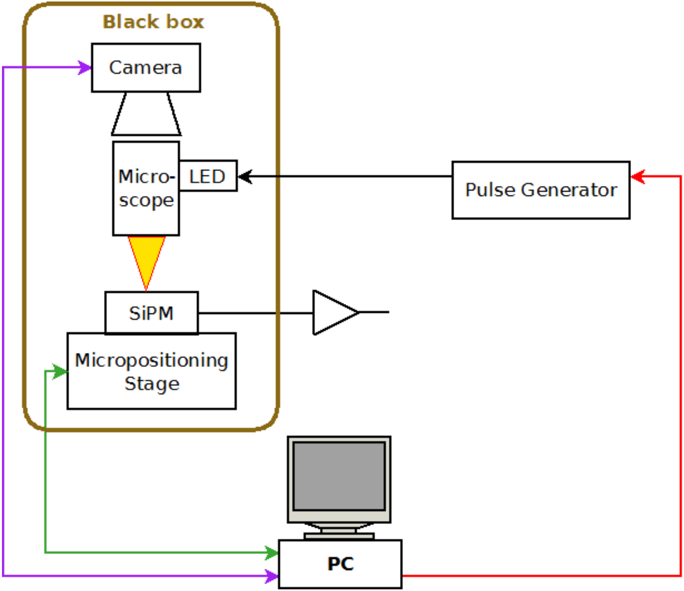

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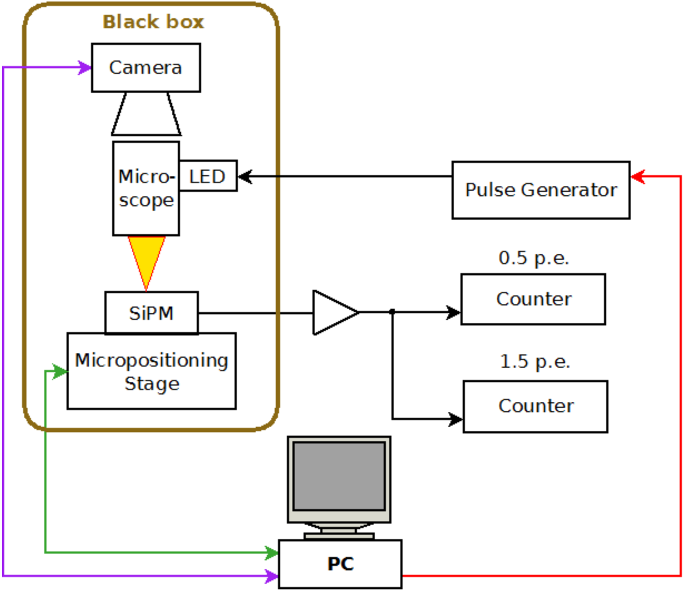

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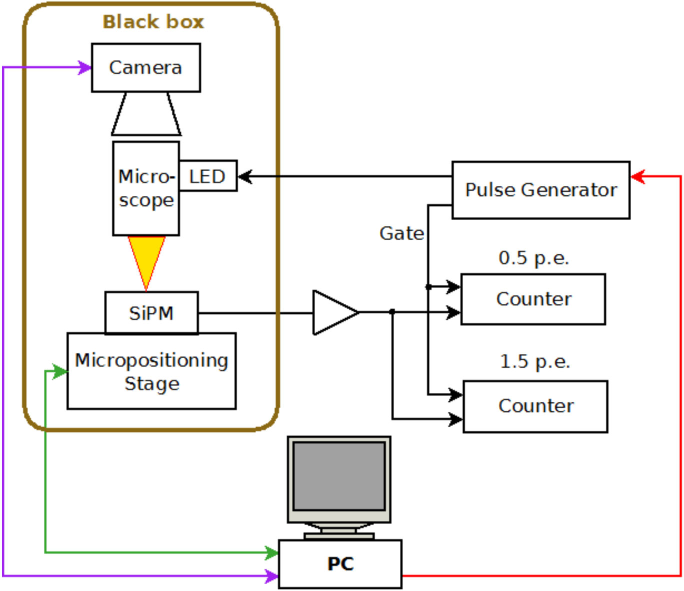

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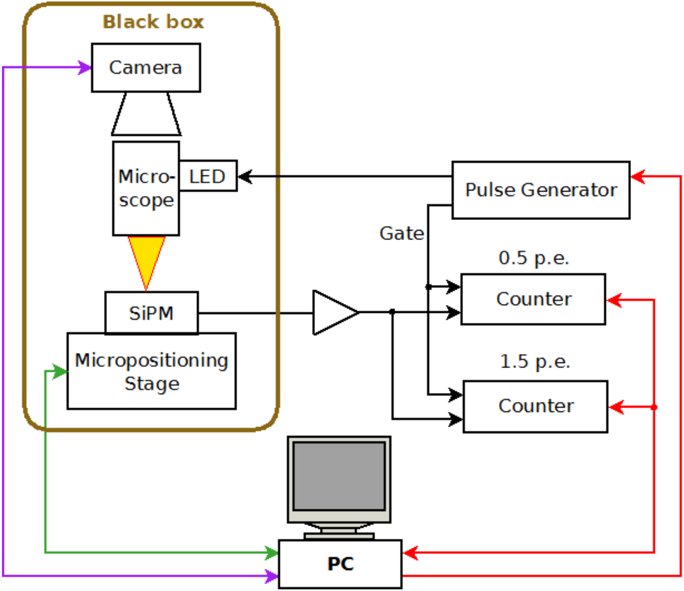


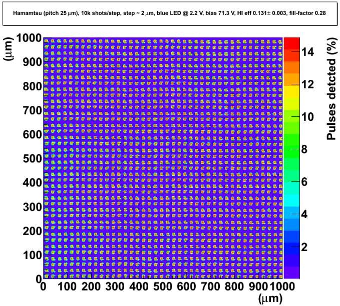
Device list

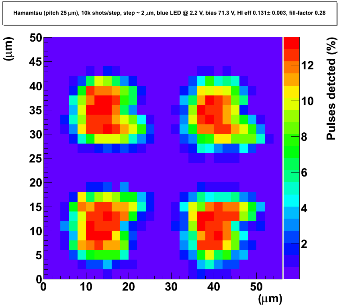
manufacturer	type	pixel pitch (μm)
Hamamatsu	S10362-11-025U, C	25
Hamamatsu	S10362-11-050U, C	50
Hamamatsu	S10362-11-100U, C	100
SENSI	SPMMicro1035X13	35
SENSI	SPMMicro1100X13	100
MEPhI/Pulsar	SiPM576#1	32
MEPhI/Pulsar	N/A	42

Table: Devices available for tests in MPI Semiconductor Lab

. . . and of course SiMPI prototypes

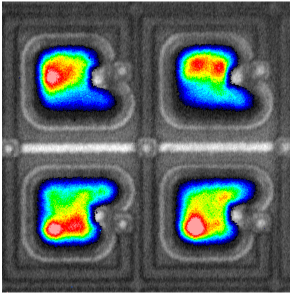
Results: Hamamatsu (MPPC) (25 μm pitch)



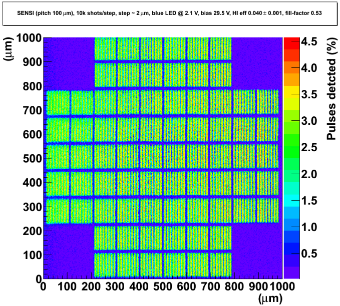


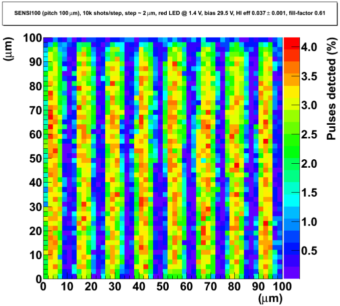
sensitive area is obviously significantly reduced by the quenching resistor placed on surface of the device

Photo + photoemission image



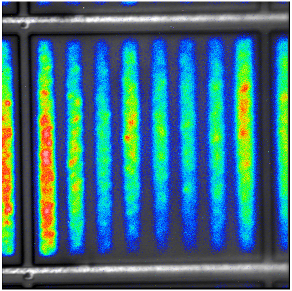
Results: SENSI (100 μm pitch)



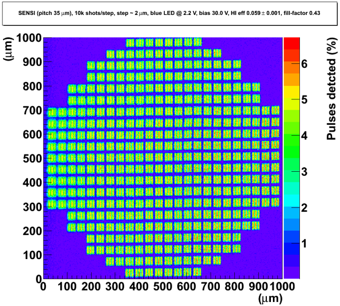


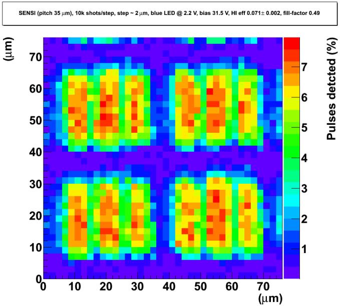
different quenching resistor shape can be observed on the sensitivity map

Photo + photoemission image



Results: SENSI (35 μm pitch)





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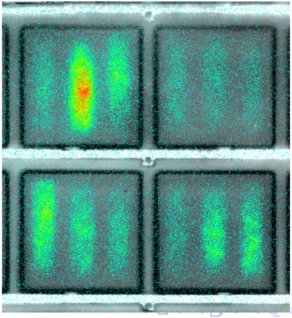
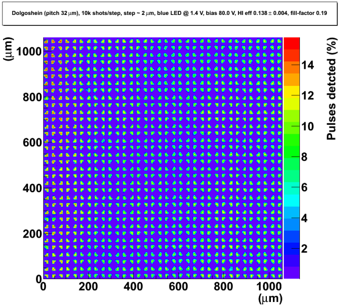
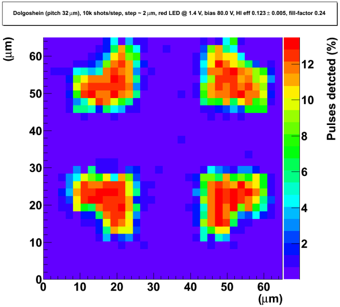


Results: MEPhi (Dolgoshein) (32 μm pitch)





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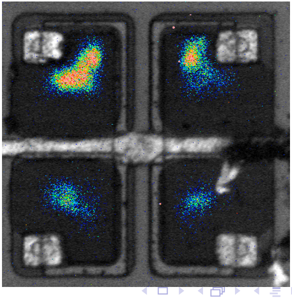


Quantities of interest

Quantities obtainable from our measurement

- noise
- fill factor (even separately for a single rectangular microcell)
- uniformity of efficiency over the device
- bias voltage dependencies of mentioned parameters

Problems

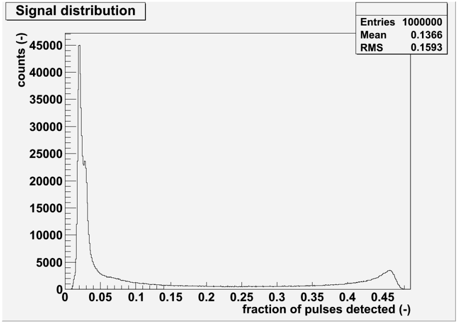
- LED light output is unknown

⇒ absolute PDE measurement is not possible

⇒ wavelength effects can be observed only qualitatively

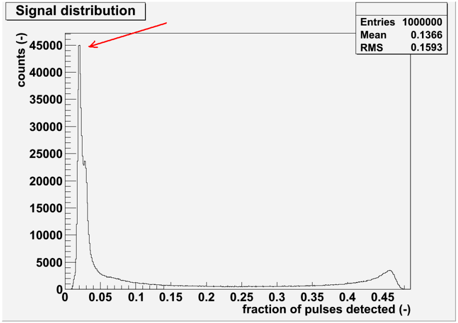
- measurements can be done only at room temperature (cooling is necessary for some devices)

Single pixel analysis procedure



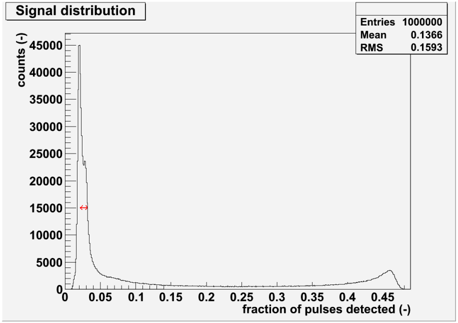
Single pixel analysis procedure

1. noise peak identified



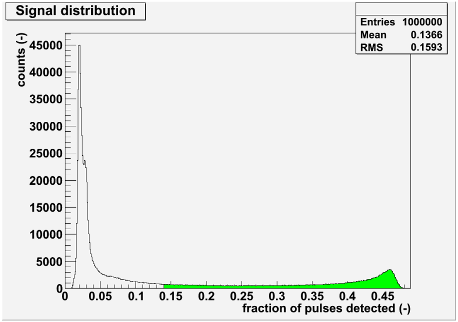
Single pixel analysis procedure

1. noise peak identified
2. half width @ 1/3 of its height calculated (HW1/3)



Single pixel analysis procedure

1. noise peak identified
2. half width @ 1/3 of its height calculated (HW1/3)
3. noise cut-off threshold set (for now to 10 × HW1/3)



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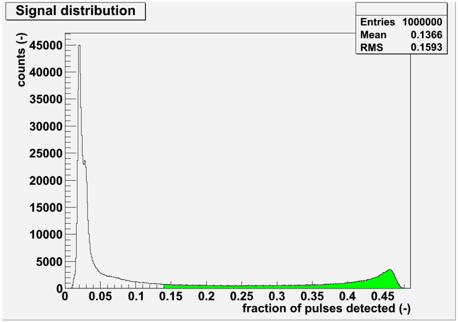
★ fill-factor can be calculated



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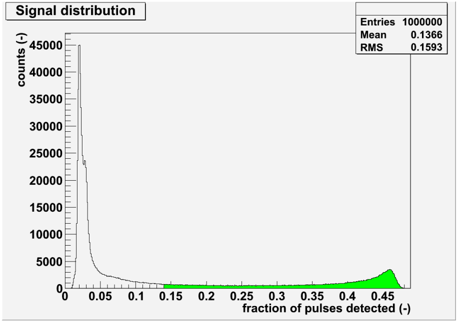
4. efficiency map cut to separate pixels



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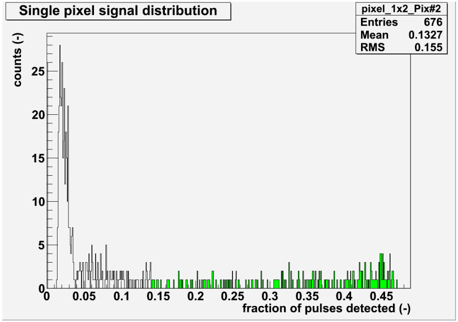
4. efficiency map cut to separate pixels
5. measured coincidences above the threshold in each pixel are integrated and scaled by entries in area of interest



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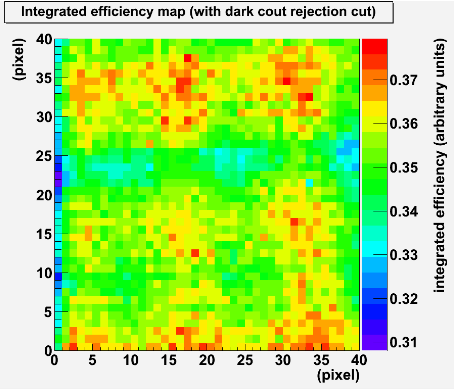
⇒ resulting values are again plot in 2D



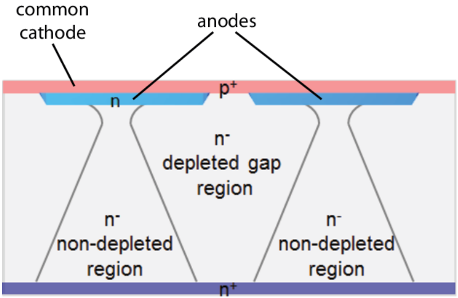
SiMPI device

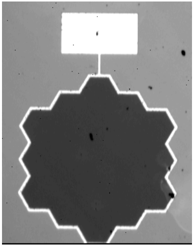
- SiMPI - Silicon MultiPixel light detector
- a non-convential concept of a SiPM
- developed and produced MPI Semiconductor Lab
- the SiMPI approach uses a technology of bulk integrated quench resistor

Goal

- simplify production process
- maximize light entrance window

SiMPI device





- common cathode for all pixels ⇒ no need of metal connections and lines on the surface
- active region is located in *n* anodes, which form pixels
- pixels are electrically separated by depleted regions formed between cathode and $n+$ backplane anode
- *n* non-depleted silicon bulk is used as a quenching resistor instead of polysilicon
- metal cathode contact surrounds active area ⇒ no obstacle for incident light

SiMPI device

Advantages

- no polysilicon quench resistor needed

⇒ simple fabrication process

- no metal within the diode matrix

⇒ no obstacles in entrance window, no parasitic capacitances

- possibility of reaching high geometrical fill-factor
- posibility of antireflective coating

Disadvantages

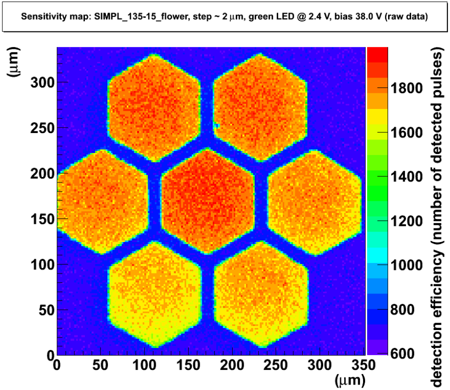
- to get proper quench resistor size, silicon wafer thickness 30-70 μm is required

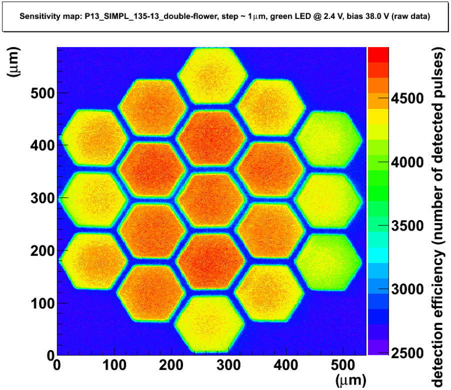
⇒ for significantly different pixel sizes, different technology and materials with different thicknesses have to be used

- the quenching resistor acts like JFET

⇒ 3-4 × longer recovery times compared to conventional SiPMs

Results: SiMPI


Sensitivity map: SIMPL_135-15_flower, step ~ 2 µm, green LED @ 2.4 V, bias 38.0 V (raw data)


Sensitivity map: P13_SIMPL_135-13_double-flower, step ~ 1µm, green LED @ 2.4 V, bias 38.0 V (raw data)

Measurements done at room temperature. Due to high dark count of 2^{nd} iteration series, it would be better to cool the devices down.

Summary & Conclusions

Achievements

- setup for uniformity characterization of SiPMs has been developed
- various types of available SiPMs can be tested
- primary measurement output is a relative sensitivity map
- further quantities as dark count and fill factor can be determined
- successfull tests of SensL, Hamamatsu, MePhi and SiMPl devices have been done

Future plans

- crosstalk scans
- study of further SiMPl prototypes
- additional cooling upgrade in development