Characterization of Silicon Photodetectors (Avalanche Photodiodes in Geiger Mode)

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Factors Affecting Response of a Silicon Photodetector

- Bias voltage (or rather overvoltage, $\Delta V = V - V_{brkd}$)
- Temperature
- Time structure of the light input
- Amplitude of the light input
- Details of the detector construction (geometrical fill factor, cross-talk suppresion)
- Others?

Goals

- Develop a complete characteristics of the detector response. Identify relevant variables.
  - For example: is $G(T,V) = G(\Delta V)$, with $V_{brkd} = V_{brkd}(T)$?
- Try to relate some of the characteristics to the detector design and construction
  - For example inter- and intra micro-pixel response uniformity
- Develop algorithm for readout strategy and calibration procedure (integration time, cross-talk, after-pulses, etc..)

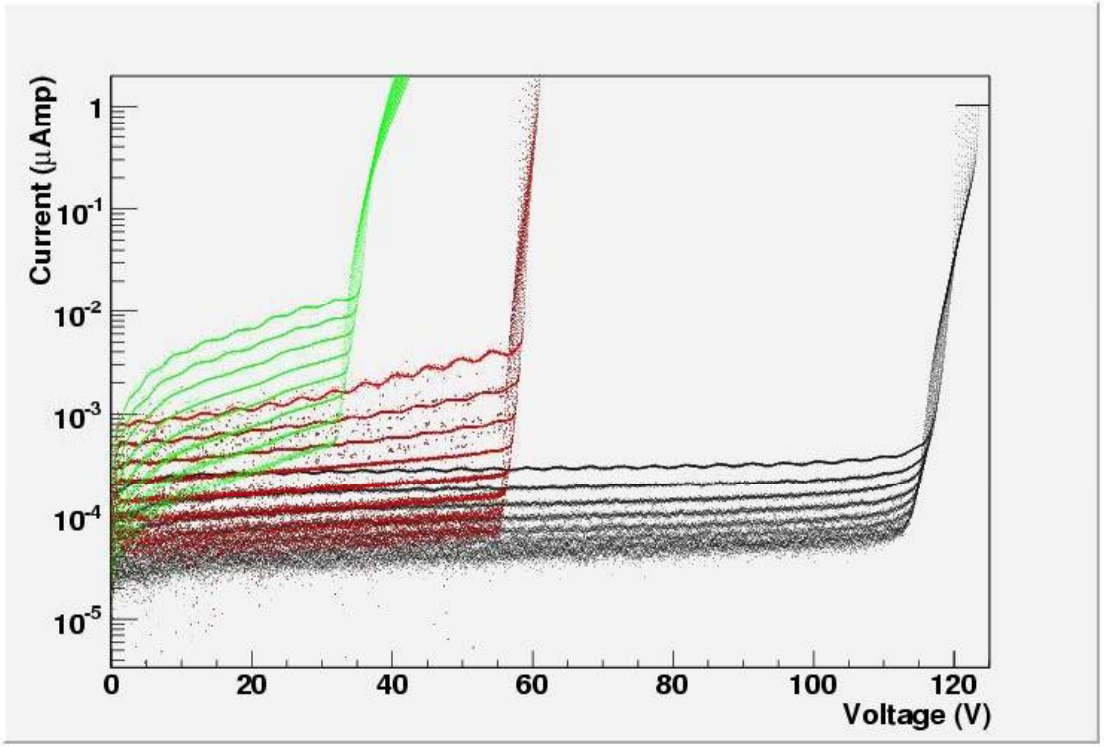
Detector Samples

- Existing
  - Hamamatsu (100, 50 and 25 μ micropixels)
  - IRST (several designs)
  - CPTA
  - Mehti
  - Dubna (two designs)
- Forthcoming
  - SensL
  - Others?

Step 1: Database of Static Characteristics

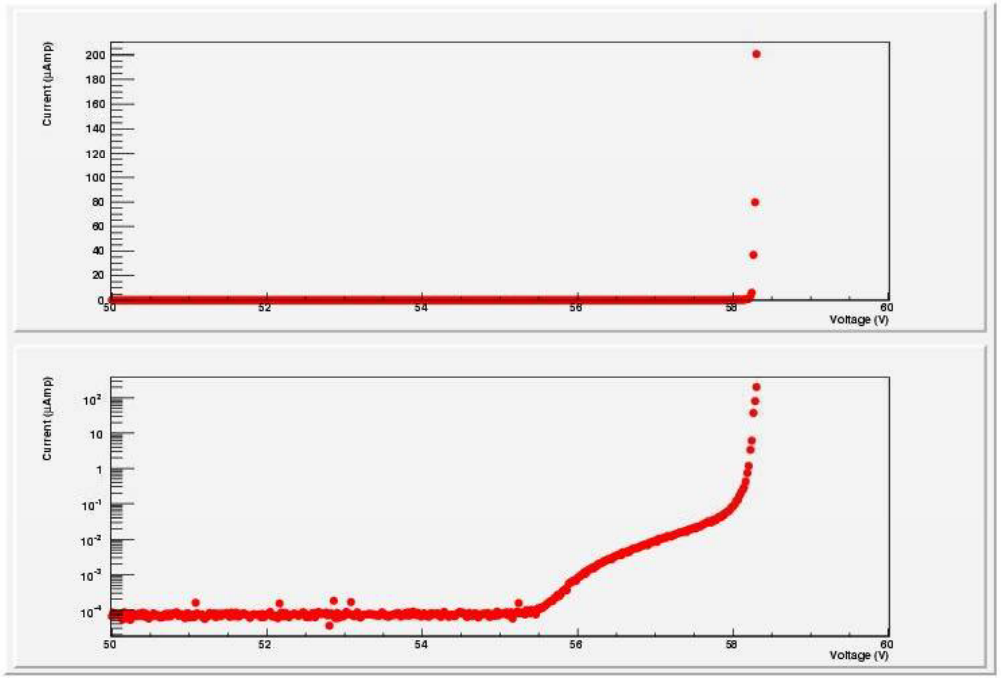
- Develop a procedure for imaging of the detector samples (SiDET facility)
- Develop an automated procedure for static characterization (breakdown voltage, resistance) as a function of the operating temperature
  - Keithley 2400 source-meter
  - Dark box
  - Peltier cold plate
  - Labview controls/readout
- Create a database of the samples, enter the static and image data

I-V Characteristics at Different Temperatures



- Different detectors have quite different operating point
- Dark current and the operating point depend on temperature

Breakdown Voltage: a Knee on the I-V plot?

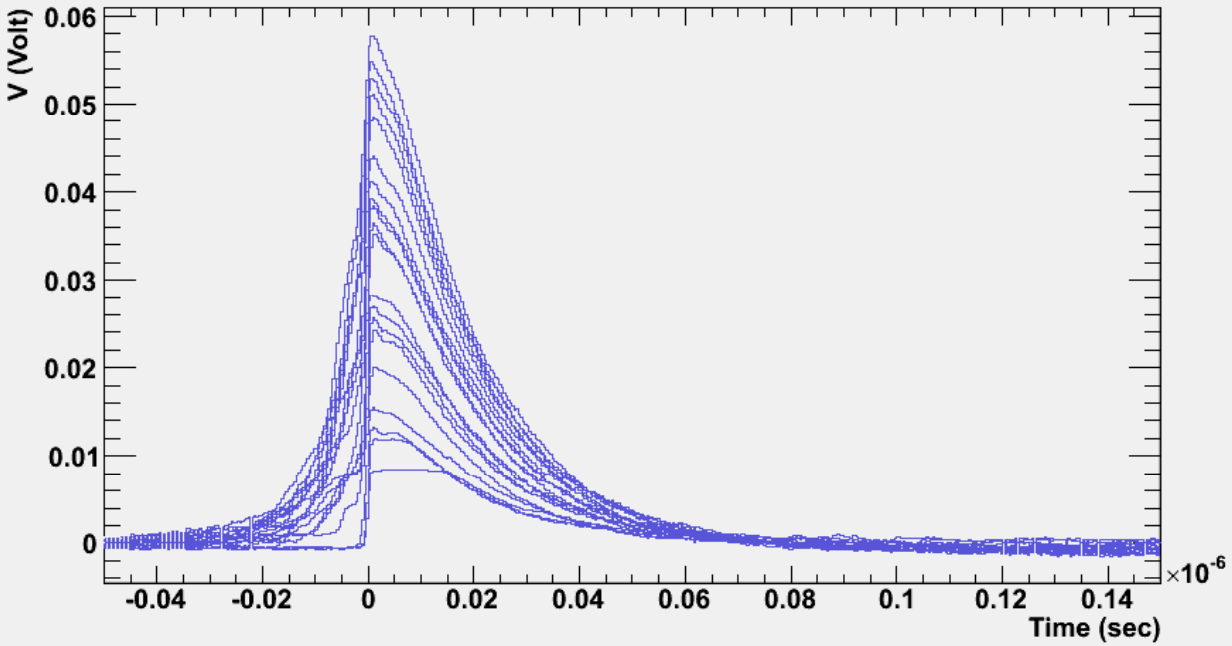


- Linear or logarithmic plot (derivative)?
- What is the shoulder on the IV log plot?
- Different pixels break-down at different voltages??
- Is it related to the resolution/width of the single electron peak??

Step 2: 'Dark Measurements' (no external light signal)

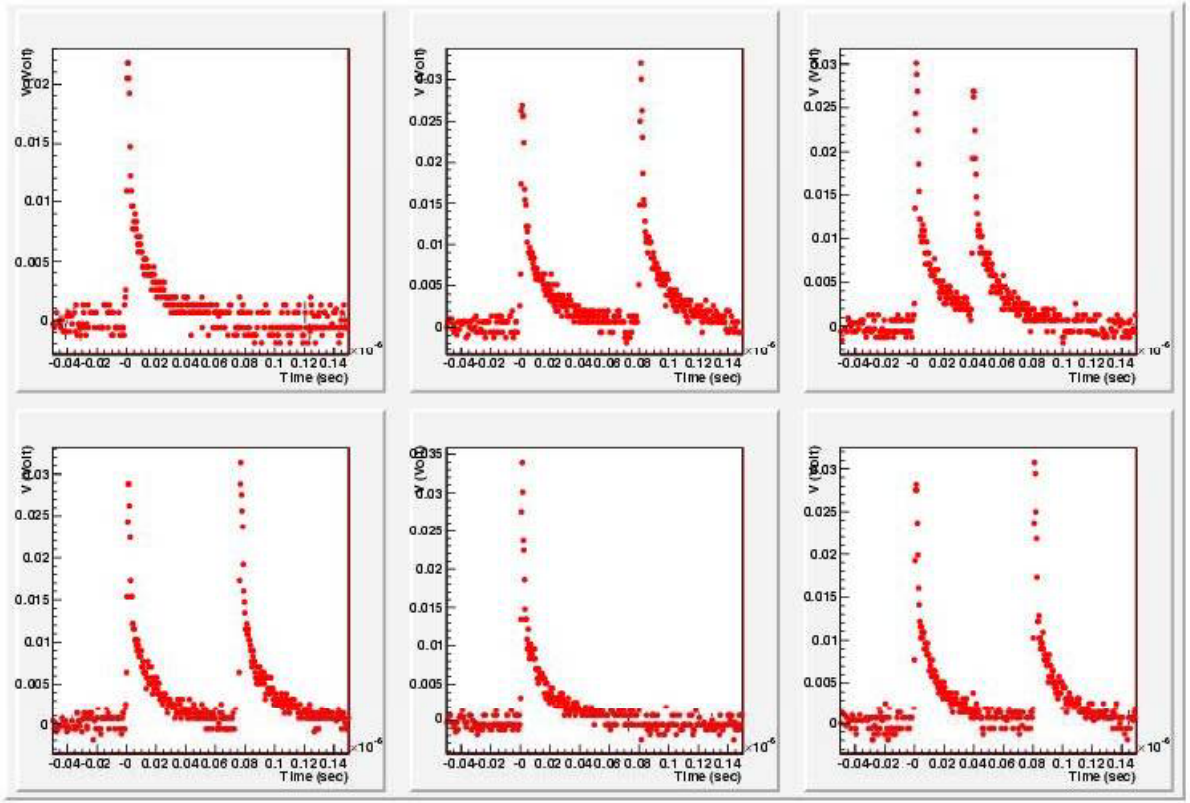
- Readout strategy:
  - Trans-conductance amplifier (MITEQ amplifiers: AU-2A-0159, AU-4A-0150, AM-4A-000110)
  - Controlled temperature:
    - Peltier creates too much of a noise
    - Chiller-based setup under construction
  - Tektronix 3000 series digital scope (5 GHz)
  - LabView DAQ and analysis program
  - Root-based analysis environment
- Dynamical characteristics of the detectors (Later: as a function of the operating temperature).
  - Rate (as a function of threshold, voltage and temperature)
  - Gain = (Charge of a single avalanche)/e (as a function of threshold, voltage and temperature)
- Examples follow (at the 'room' temperature) …

Average Pulse Shapes for Different Thresholds



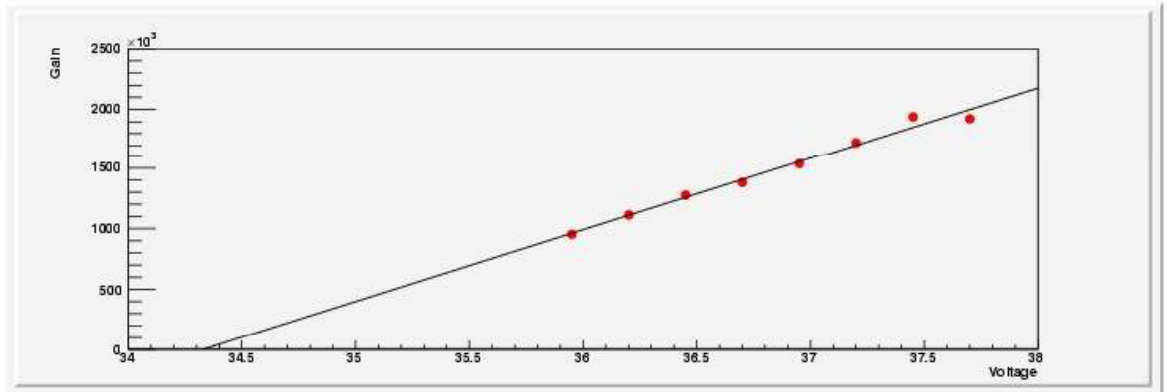
- But… average does not necessarily represent the real pulses

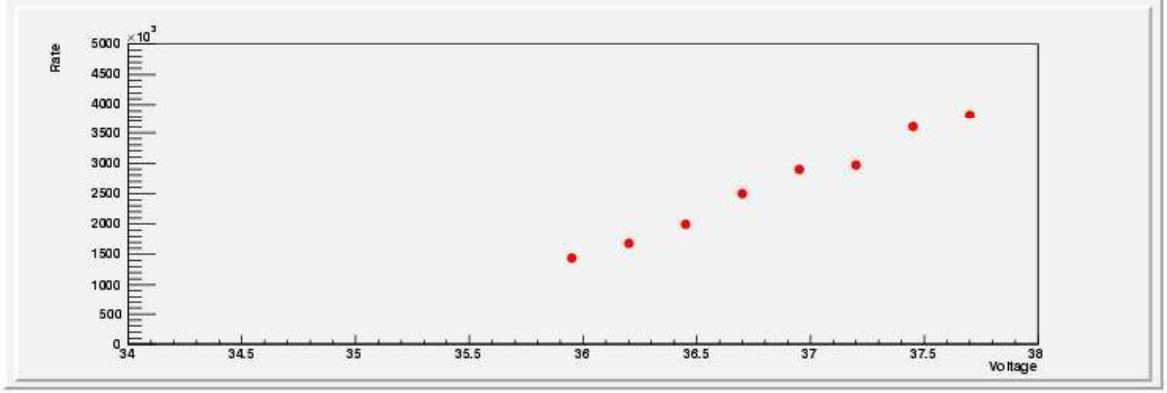
Examples of Real Pulses



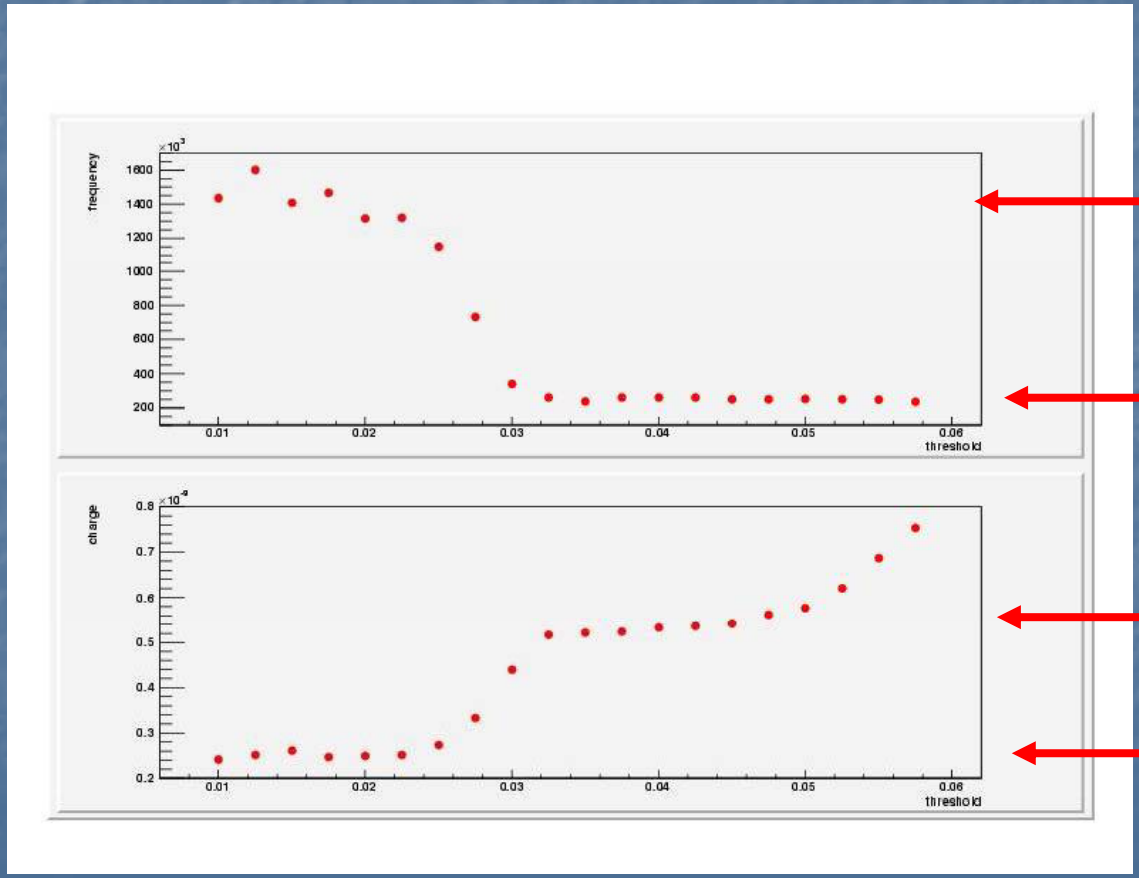
- Afterpulses and/or cross-talk
- ~ 5-10% (depending on voltage)
- Time constant of tens of nanoseconds

Gain and Rate as a Function of Voltage





Rate and Charge as a Function of Trigger Threshold



Single avalanche

Double avalanche

Double avalanche

Single avalanche

Step 3: Characterization of the Detector Response to a Calibrated Light Pulse

- Light source (under construction):
  - Short pulse duration (<1 nsec)
  - Absolute light calibration (modified scheme of P. Gorodetzky)
  - Variable light intensity (0.1 – 1000 photons)
- Readout and analysis scheme (as before)
- As a function of voltage and temperature:
  - PDE
  - Linearity of the 'prompt' response (~5 nsec gate)
  - The rate, time and amplitude distribution of 'follow-up' pulses (as a function of the light intensity)

Step 4: Microscopic Studies of the Photodetector (Planned)

- Focused (calibrated) light source, 2-3 μ spot size (Selcuk C.)
- Microstage (<1 μ stepping accuracy)
- Dark box containing the detector, focusing lenses and the stage
- Readout as before
- Spatial characteristics of the photodetector, intra and inter-micro pixel variation of:
  - Gain
  - PDE
  - Afterpulses
  - Cross-talk