Electrical Properties of MPPC/SiPM/GMAPD's

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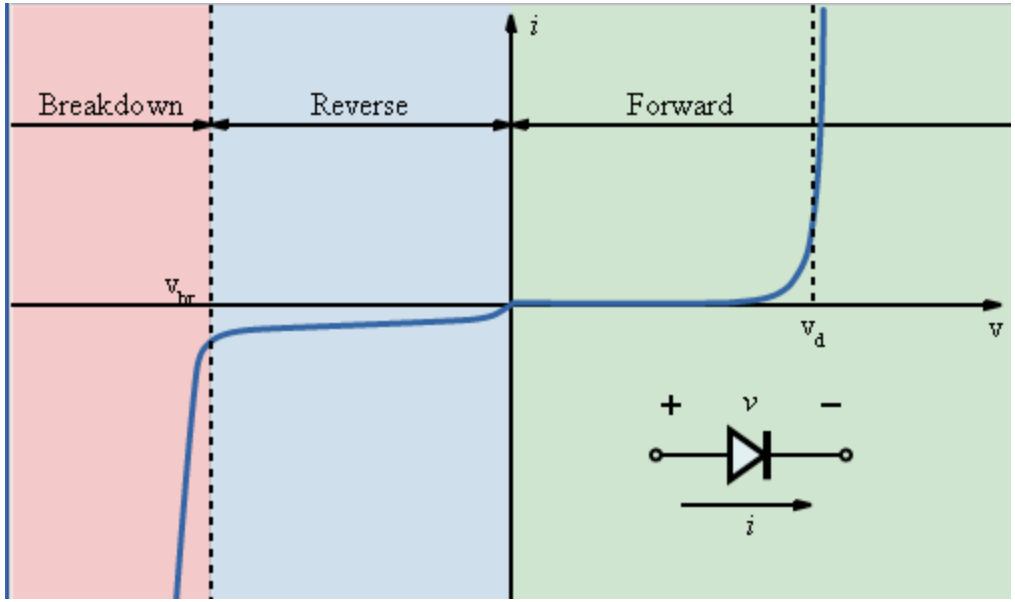
Motivation

- MPPC/SiPM/GMAPD are avalanche diodes biased in the reverse direction and operated in a Geiger mode (so we think)
- Their behavior depends on the electrical properties of a cell: resistance and capacitance, hence it is important to measure these properties for different detectors we are trying to understand
- Detectors:
  - 1 mm x 1 mm, 20μ pixel 025U, 50μ pixel 050U, 100μ pixel (100U)
  - 3 mm x 3 mm, 50μ pixel, 050PX

Ideal Diode (Shockley)

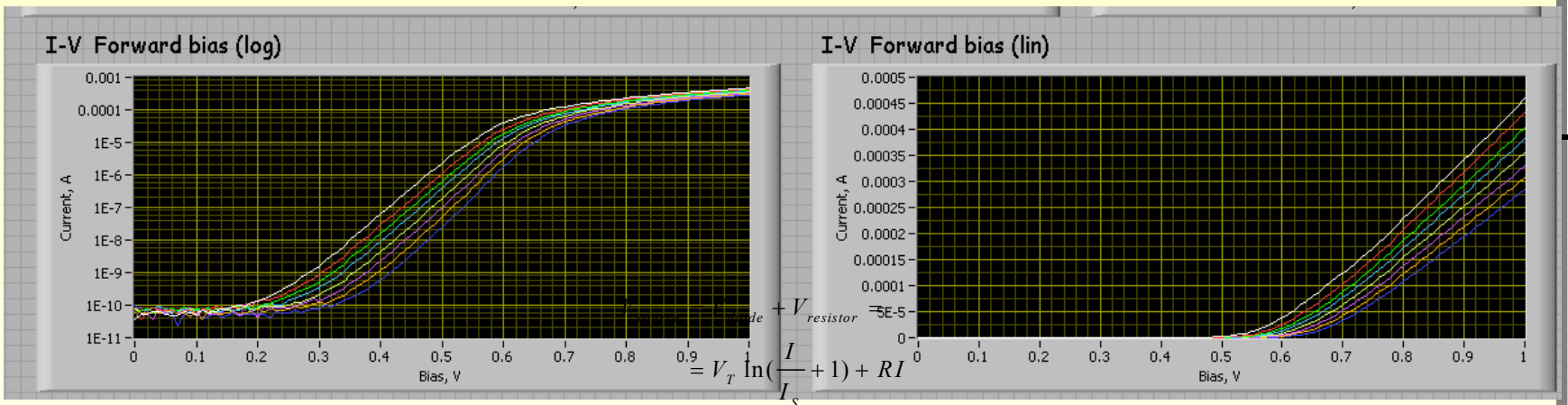


$$I = I_S \left(e^{V_D/(nV_T)} - 1\right),$$ Current in the forward direction, where

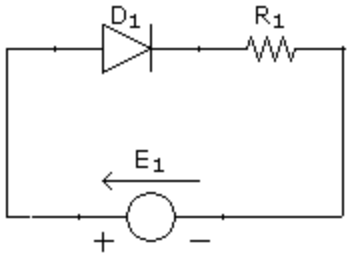
$$V_T = \frac{kT}{q},$$ thermal voltage

$$I_S = eA\left(\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} + \sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A}\right),$$ saturation current

I-V Curve for a Real Detector



$$= V_T \ln(\frac{I}{I_S} + 1) + RI$$

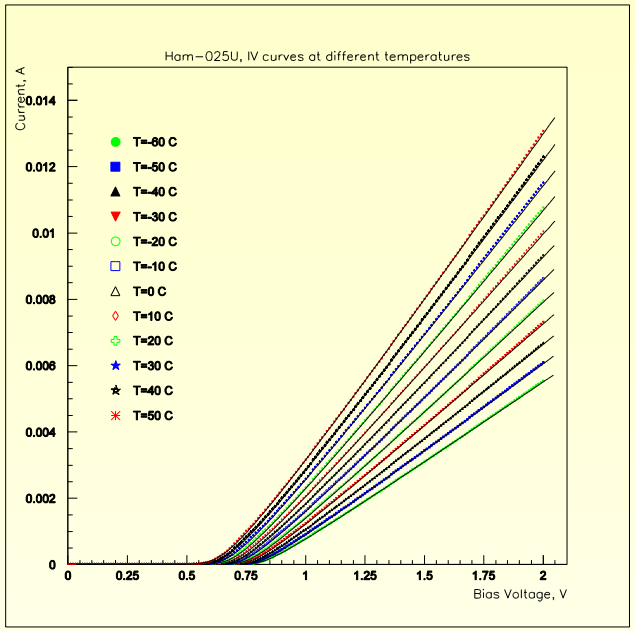


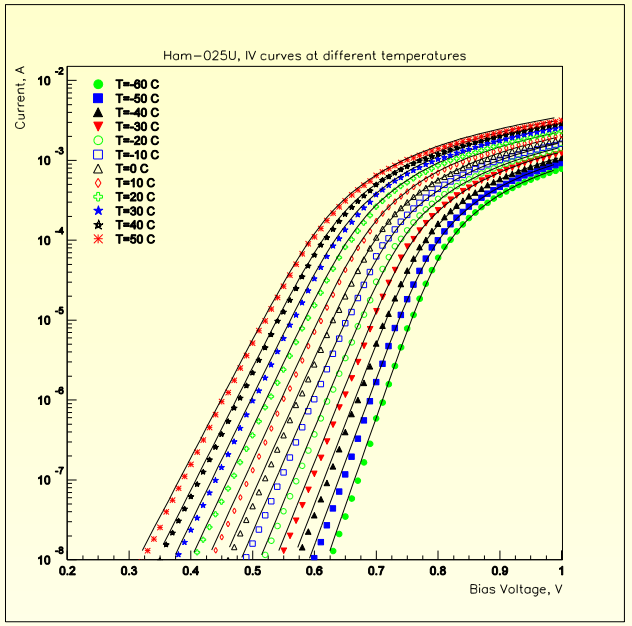
We have a quenching resistor in series with the diode

$$V_{source} = V_{diode} + V_{resistance} = V_T \ln(\frac{I}{I_S} + 1) + RI$$

HAMAMATSU 025U

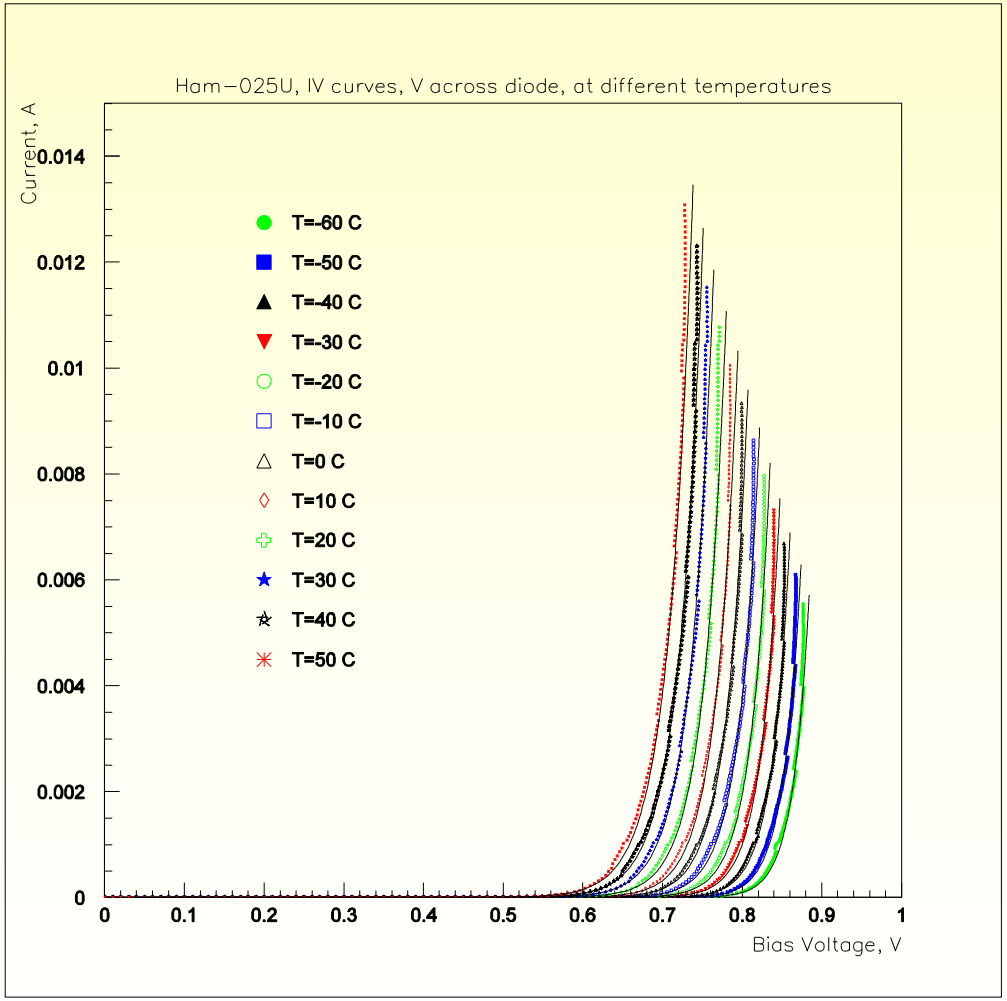
1 mm x 1 mm, 1600 pixels



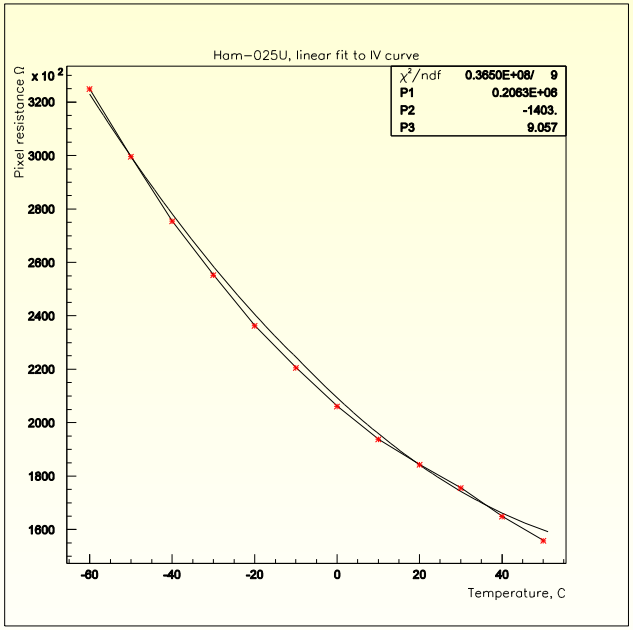


- the same data in a linear and logarithmic scale
- I-V characteristics measured at temperatures from -60C to +50C
- Shockley equation provides a very good description of the measured I-V curves over 5 orders of magnitude
- slopes of the lines on a linear plot => total resistance
- Assuming the parasitic resistance is small, the quenching resistance $R_q = N_{pixel} \times R_{dev}$
- slopes of the lines on the log plots => thermal voltage
- vertical offset on the logarithmic plot => saturation current
- all parameters change with temperature

I-V Diode Only

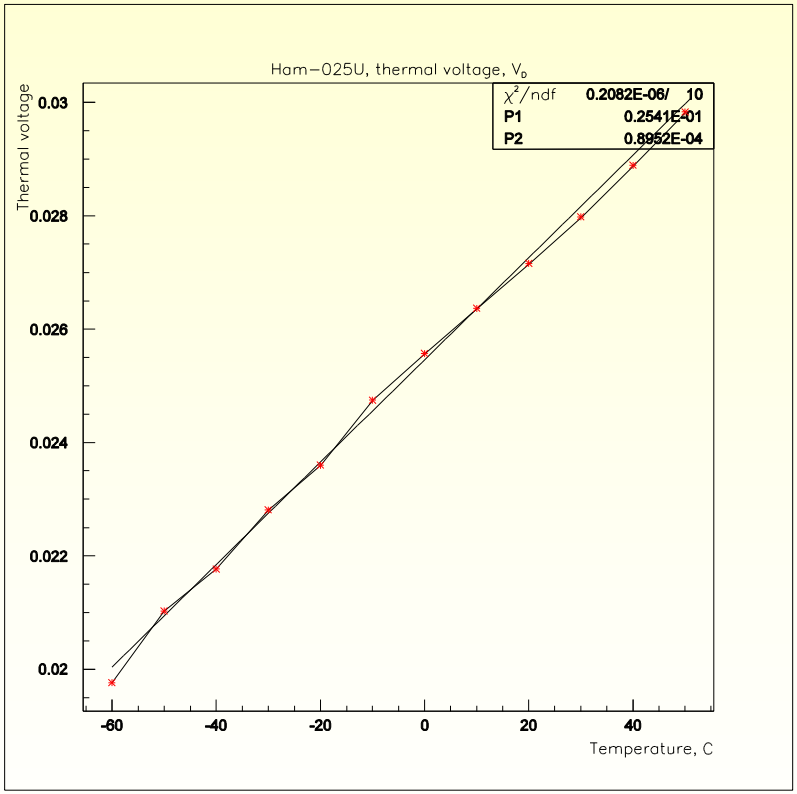


Quenching Resistance



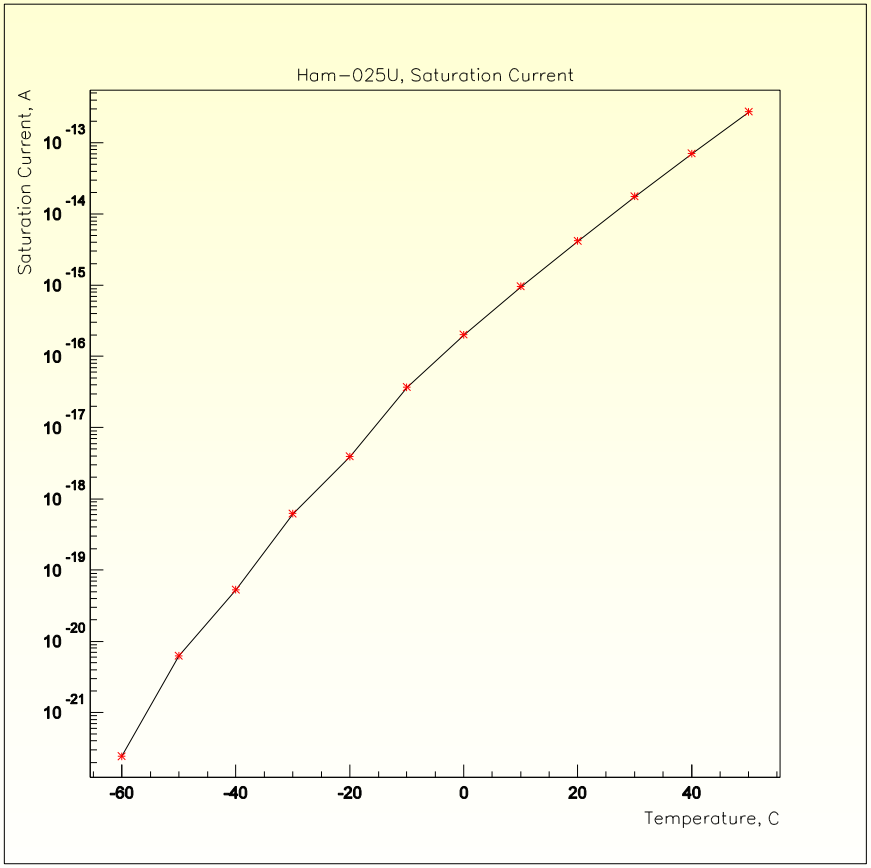
Quenching resistor gets smaller as the temperature rises (polysilicon!)
Non-linear dependence of the quenching resistance on temperature

Thermal Voltage



- fitted values of the thermal voltage change linearly with temperature, as expected
- quenlity factor n very close to 1 (1.04)

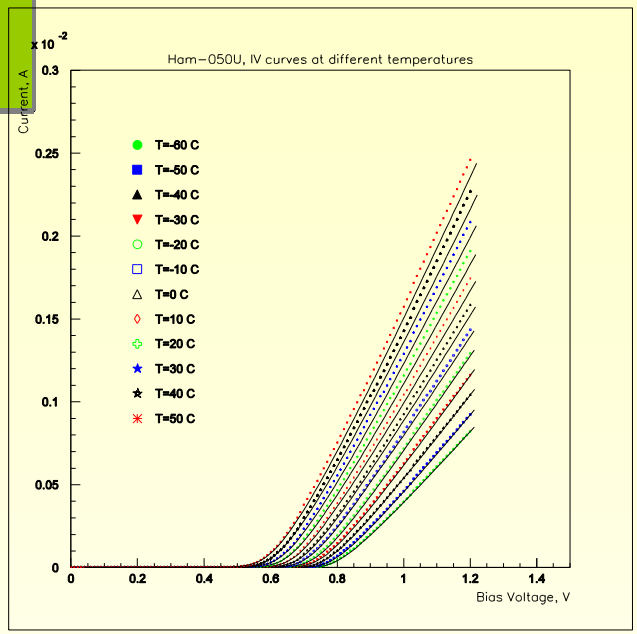
Saturation Current

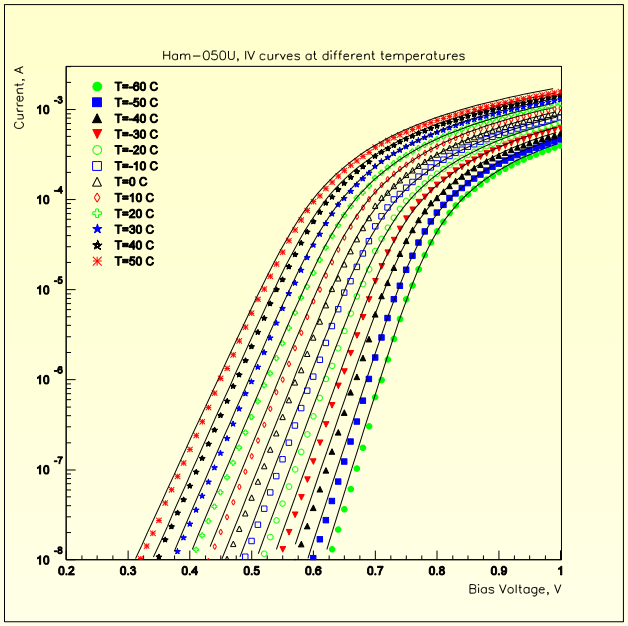


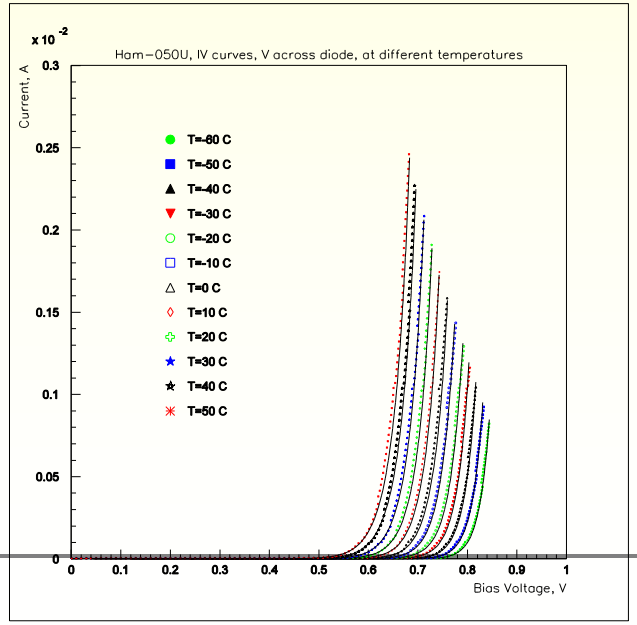
Saturation current varies by 10 orders of magnitude. Presumably related to dark pulses rates

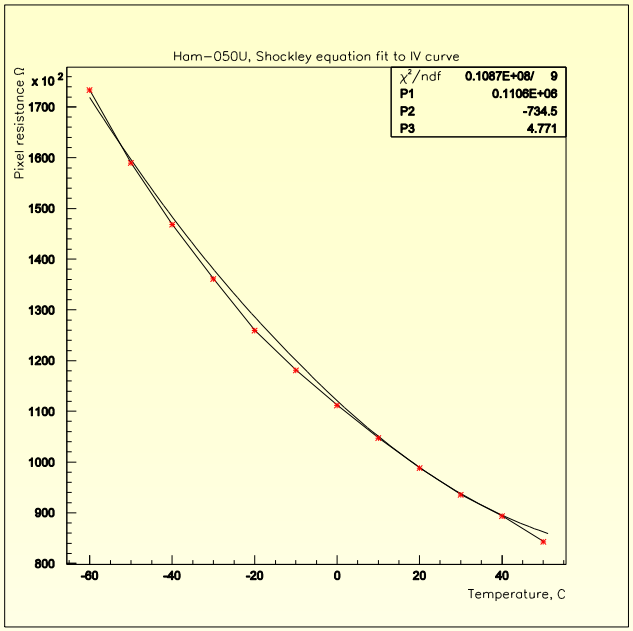
HAMAMATSU 050U

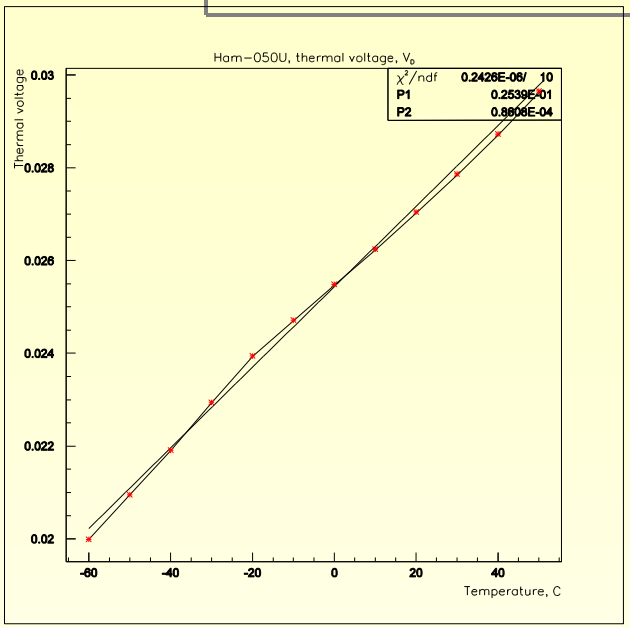
1 mm x 1 mm, 400 pixels

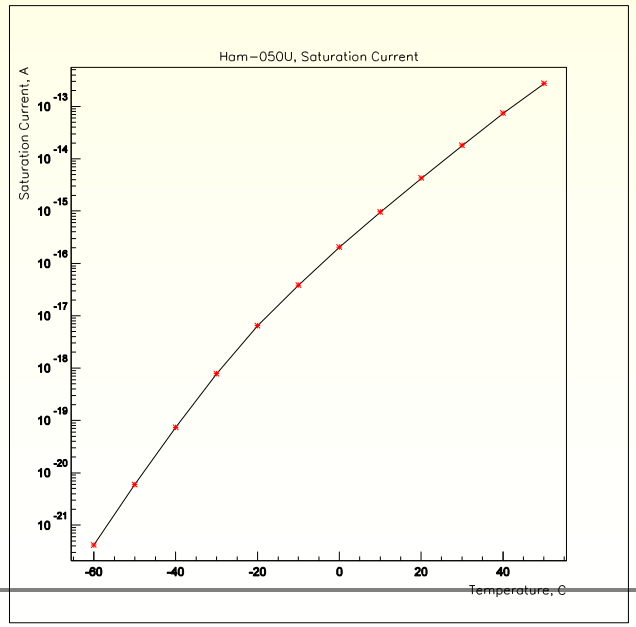

Ham−050U, IV curves at different temperatures
x 10 -2
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham−050U, IV curves at different temperatures
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham−050U, IV curves, V across diode, at different temperatures
x 10 -2
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C

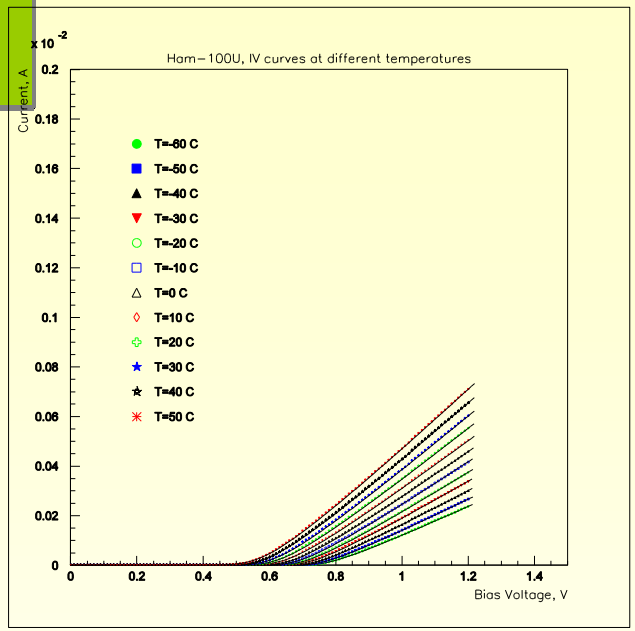

Ham−050U, Shockley equation fit to IV curve
Pixel resistance Ω
x 10 2
1700
1600
1500
1400
1300
1200
1100
1000
900
800
-60
-40
-20
0
20
40
Temperature, C
χ²/ndf 0.1087E+08/ 9
P1 0.1106E+08
P2 -734.5
P3 4.771

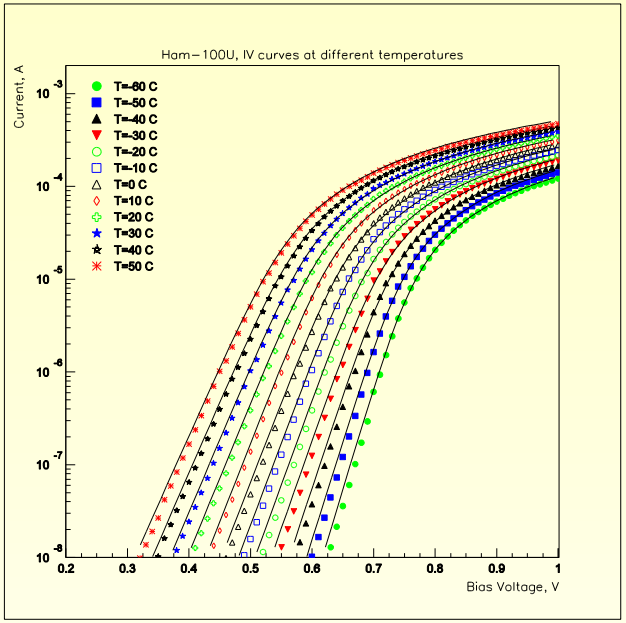

Ham−050U, thermal voltage, V₀
Thermal voltage
0.03
0.028
0.026
0.024
0.022
0.02
-60
-40
-20
0
20
40
Temperature, C
χ²/ndf 0.2426E-06/ 10
P1 0.2539E-01
P2 0.8608E-04

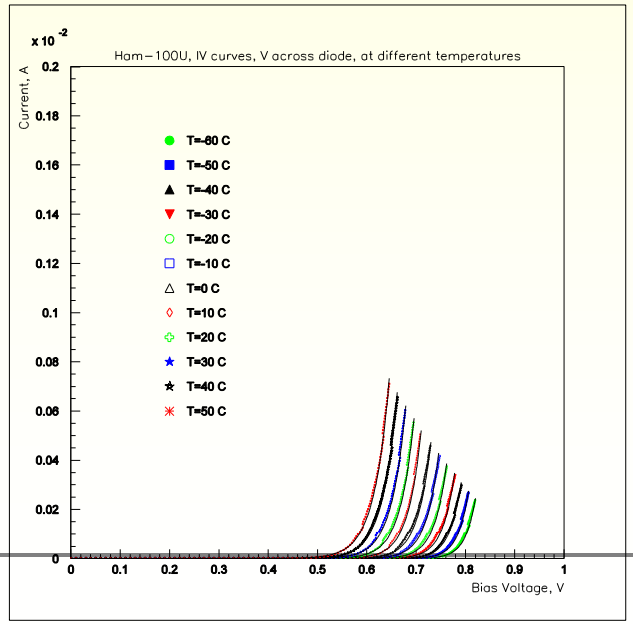

Ham−050U, Saturation Current
Saturation Current, A
10 -13
10 -14
10 -15
10 -16
10 -17
10 -18
10 -19
10 -20
10 -21
-60
-40
-20
0
20
40
Temperature, C

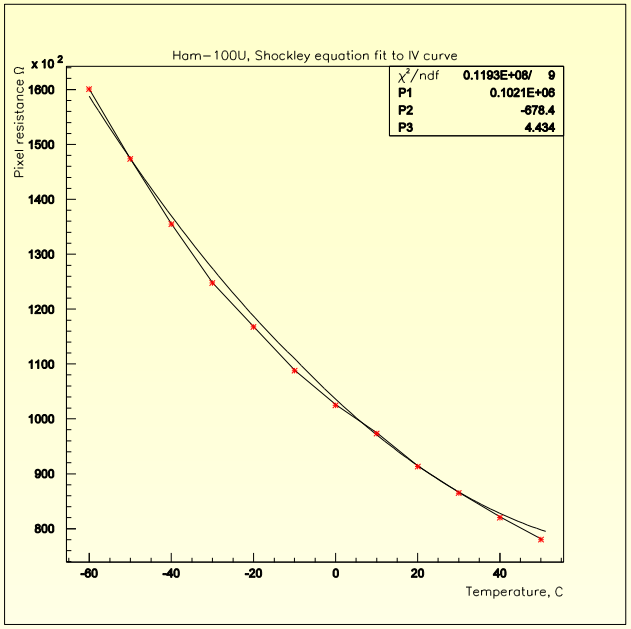
HAMAMATSU 100U

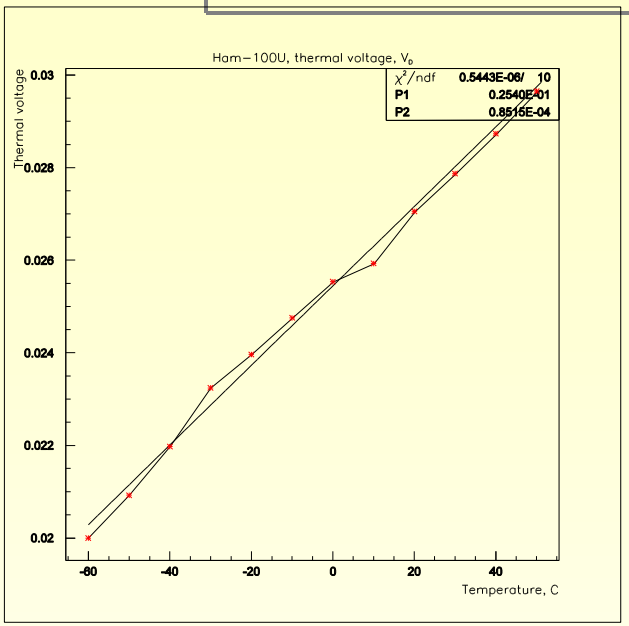
1 mm x 1 mm, 100 pixels

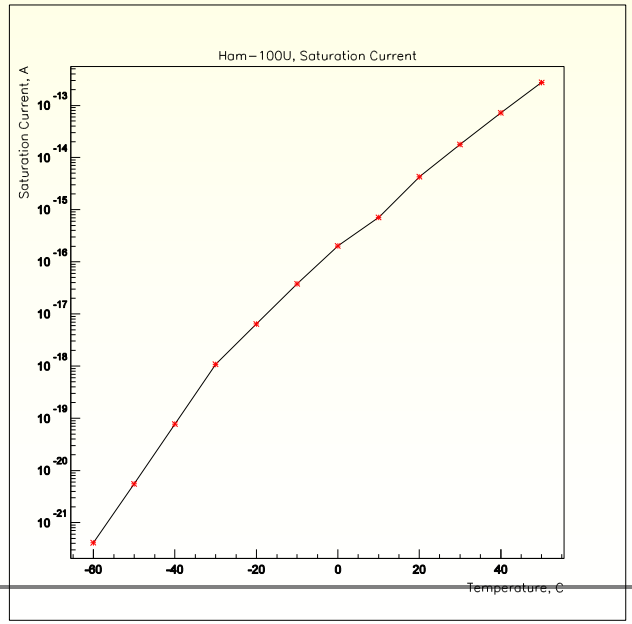

Ham−100U, IV curves at different temperatures
x 10 -2
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C

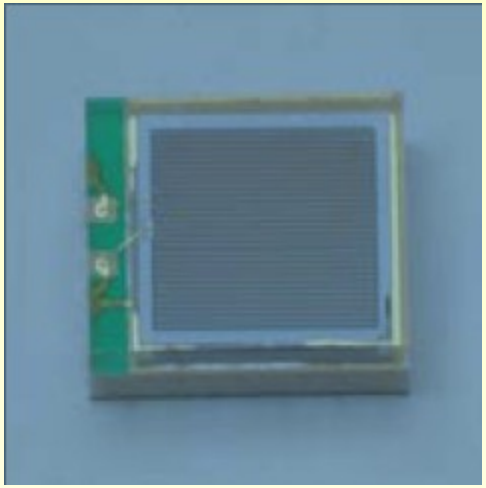

Ham−100U, IV curves at different temperatures
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham−100U, IV curves, V across diode, at different temperatures
x 10 -2
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham−100U, Shockley equation fit to IV curve
Pixel resistance Ω
x 10 2
Temperature, C
χ²/ndf 0.1193E+08/ 9
P1 0.1021E+06
P2 -678.4
P3 4.434

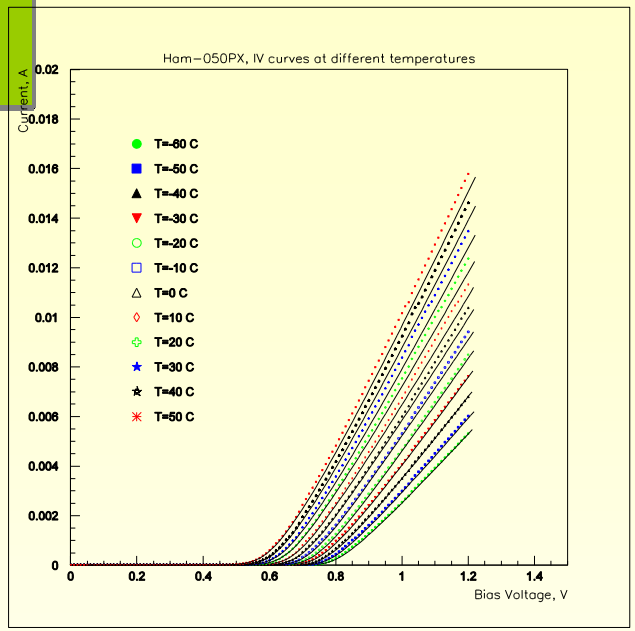

Ham−100U, thermal voltage, V0
Thermal voltage
Temperature, C
χ²/ndf 0.5443E-06/ 10
P1 0.2540E-01
P2 0.8515E-04

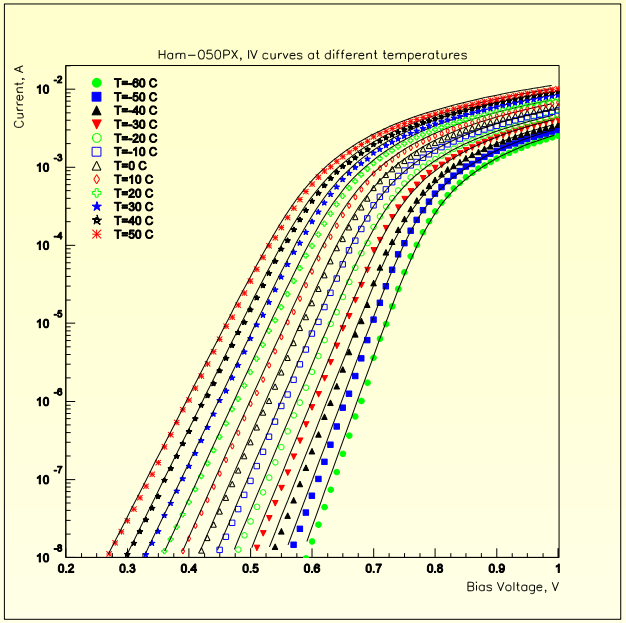

Ham−100U, Saturation Current
Saturation Current, A
Temperature, C

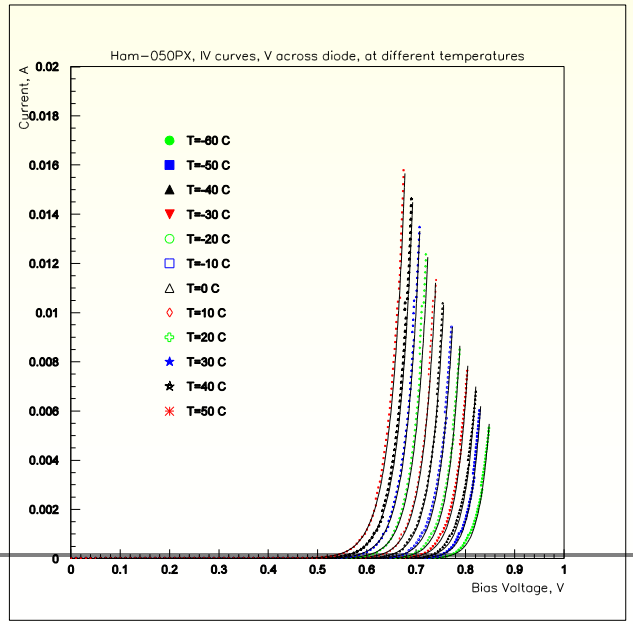


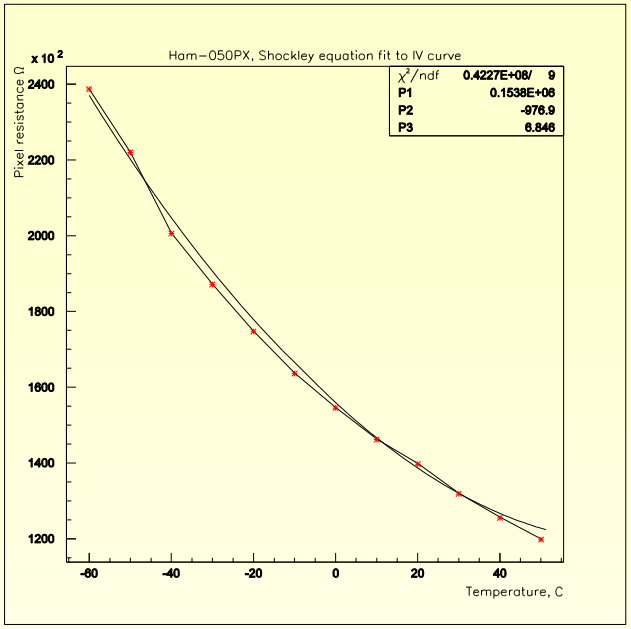
HAMAMATSU 050PX

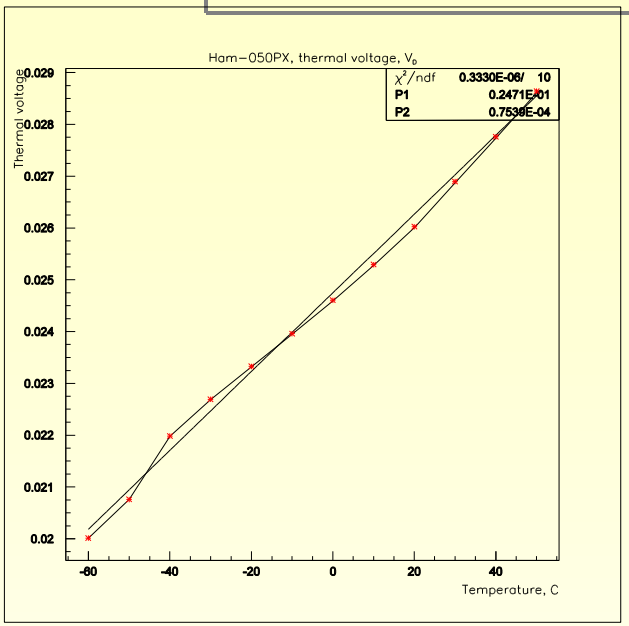
3 mm x3 mm, 3600 pixels

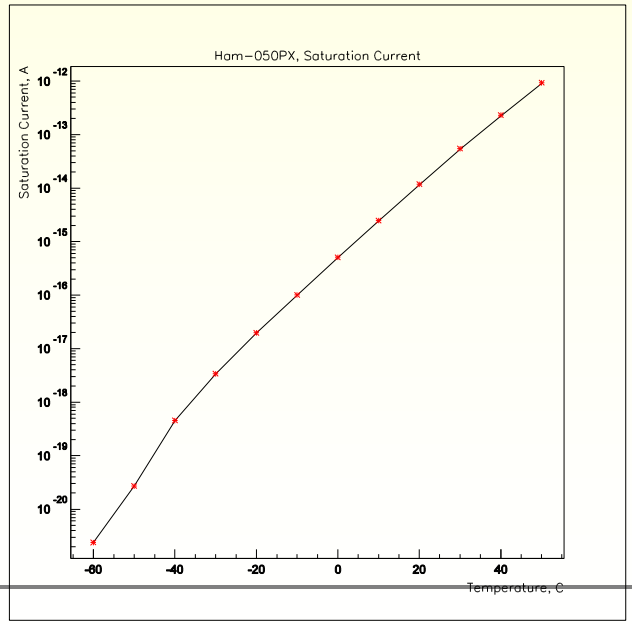

Ham-050PX, IV curves at different temperatures
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham-050PX, IV curves at different temperatures
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C


Ham-050PX, IV curves, V across diode, at different temperatures
Current, A
Bias Voltage, V
T=-60 C
T=-50 C
T=-40 C
T=-30 C
T=-20 C
T=-10 C
T=0 C
T=10 C
T=20 C
T=30 C
T=40 C
T=50 C

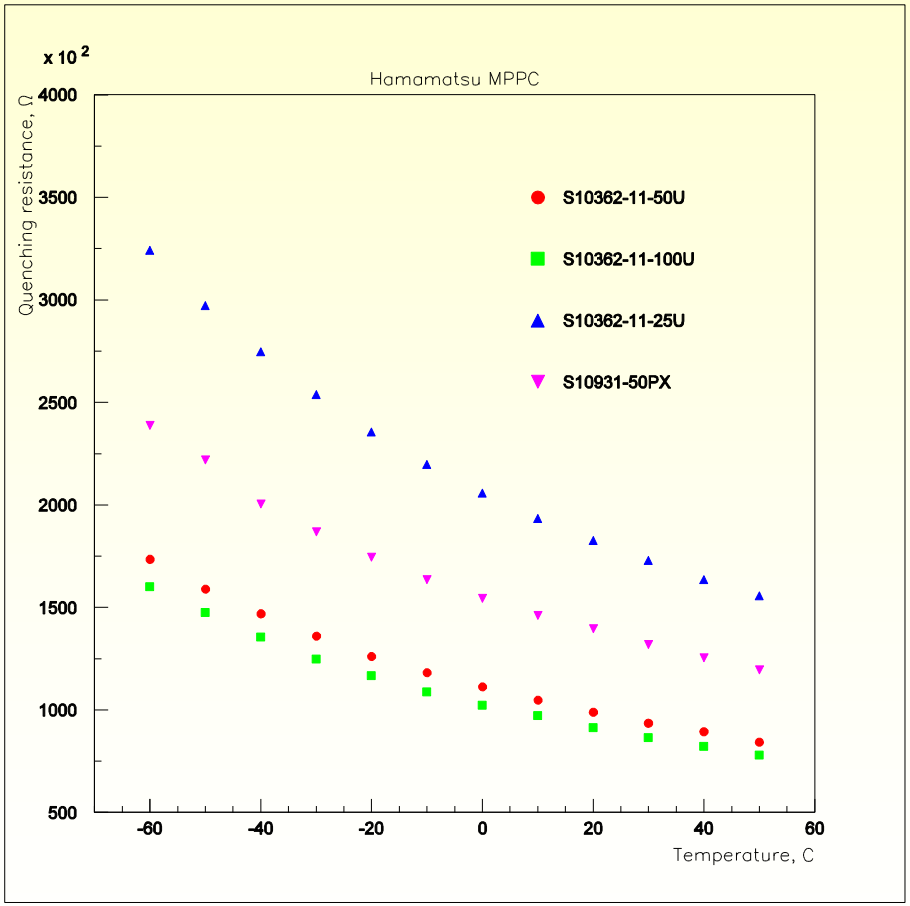

Ham−050PX, Shockley equation fit to IV curve
x 10 2
Pixel resistance Ω
χ²/ndf 0.4227E+08/ 9
P1 0.1538E+06
P2 -976.9
P3 6.846
2400
2200
2000
1800
1600
1400
1200
-60
-40
-20
0
20
40
Temperature, C


Ham−050PX, thermal voltage, V0
Thermal voltage
χ²/ndf 0.3330E-06/ 10
P1 0.2471E-01
P2 0.7539E-04
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
-60
-40
-20
0
20
40
Temperature, C


Ham−050PX, Saturation Current
Saturation Current, A
10 -12
10 -13
10 -14
10 -15
10 -16
10 -17
10 -18
10 -19
10 -20
-60
-40
-20
0
20
40
Temperature, C

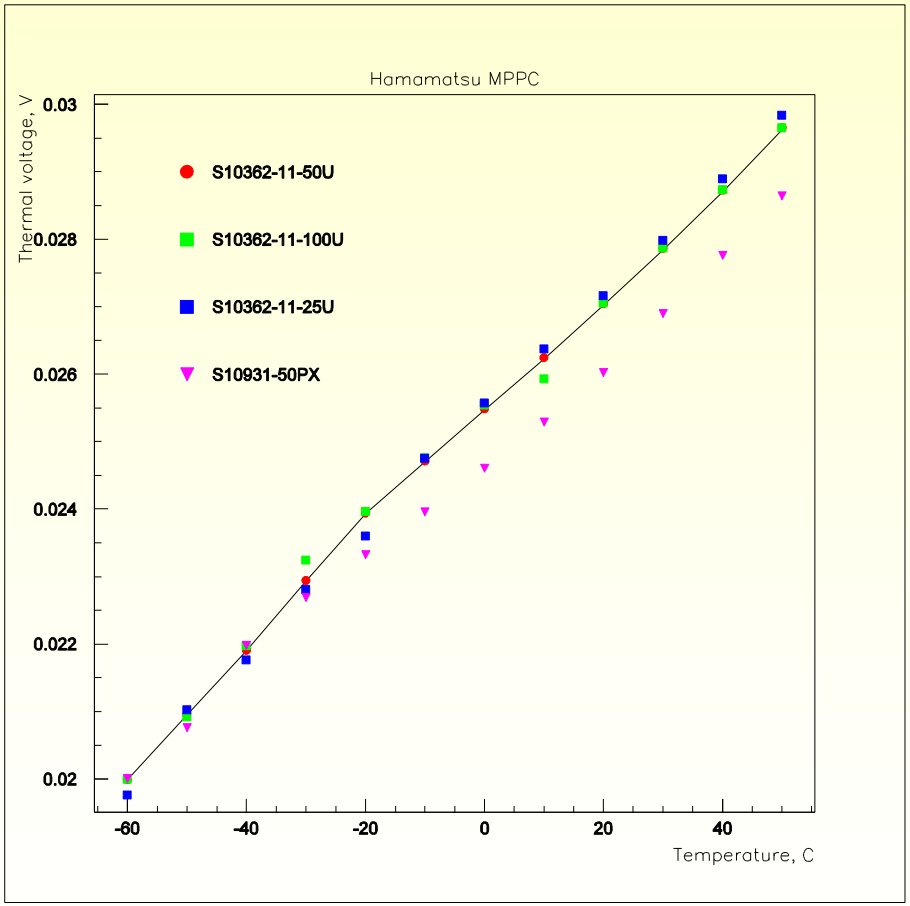
COMPARISON OF DETECTORS

Quenching Resistance



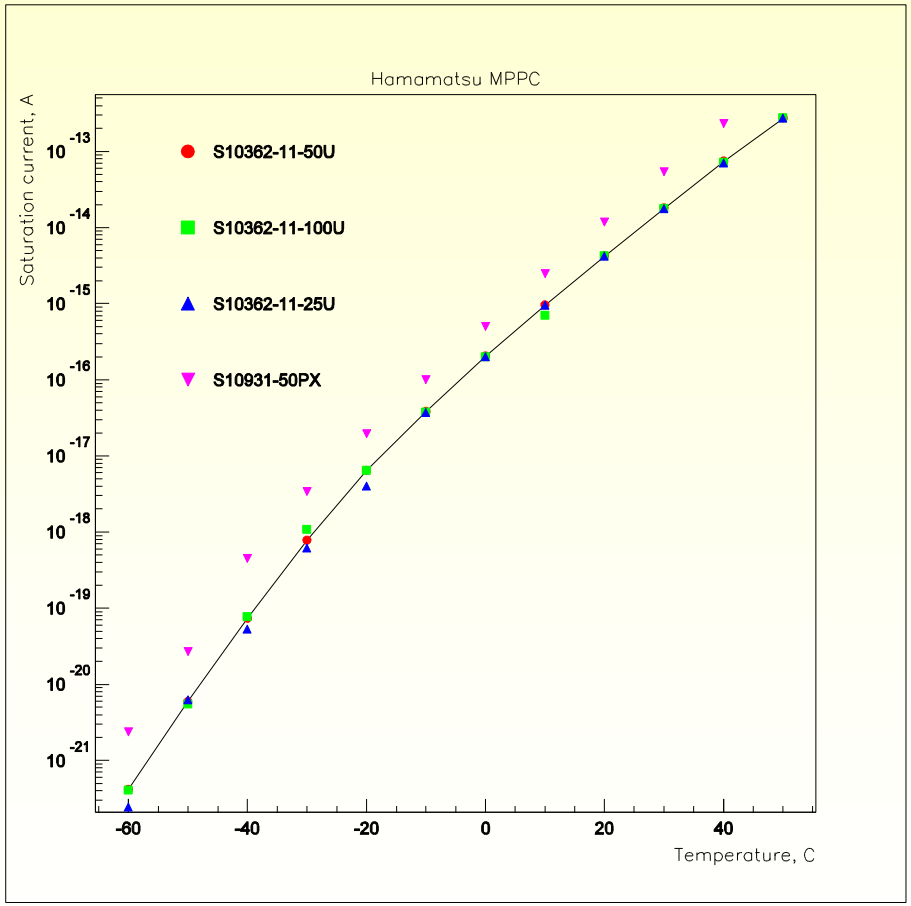
- 50U and 100U have very similar quenching resistor
- 25U has about twice as big
- 50PX has the resistor 50% higher then 50U

Thermal Voltage



- 25U, 50U and 100U have 'the same diode'
- 50PX diode seems to be somewhat different

Saturation Current



- 25U, 50U and 100U have 'the same diode'
- 50PX diode seems to be somewhat different