Status of the Avalanche Photodiodes for the CMS Electromagnetic Calorimeter

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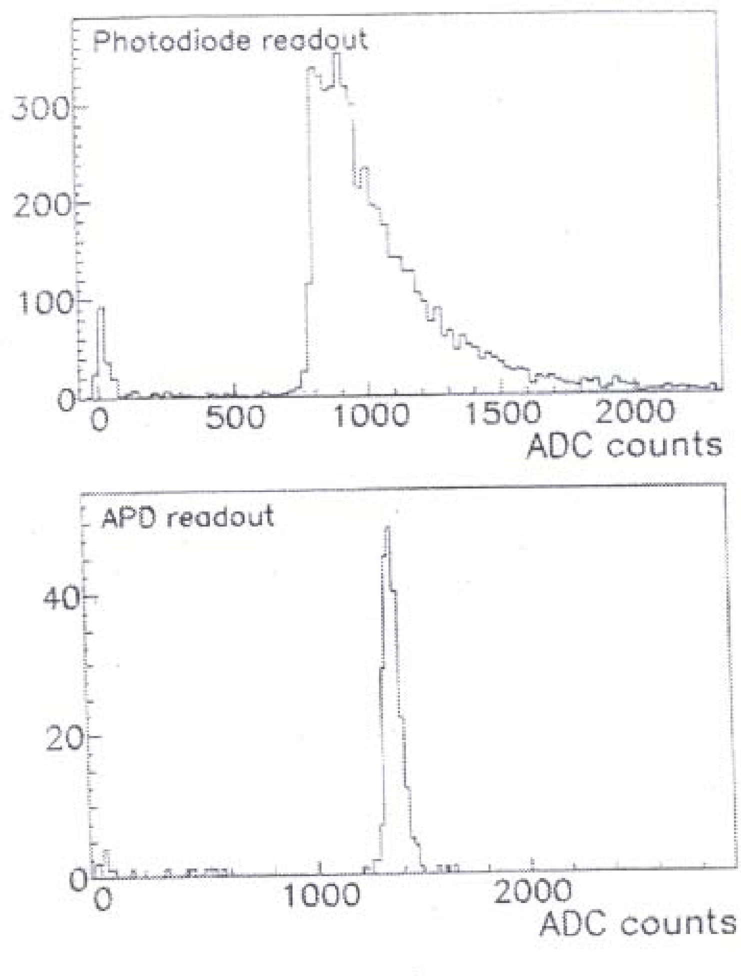
After 5 years of R&D work the Avalanche Photodiodes for CMS produced by Hamamatsu Photonics have now excellent electrical and optical properties. During the startup of the mass production problems with the reliability and with the radiation hardness have been found. The reasons were identified and counter-measures have been applied.

Properties of Avalanche Photodiodes

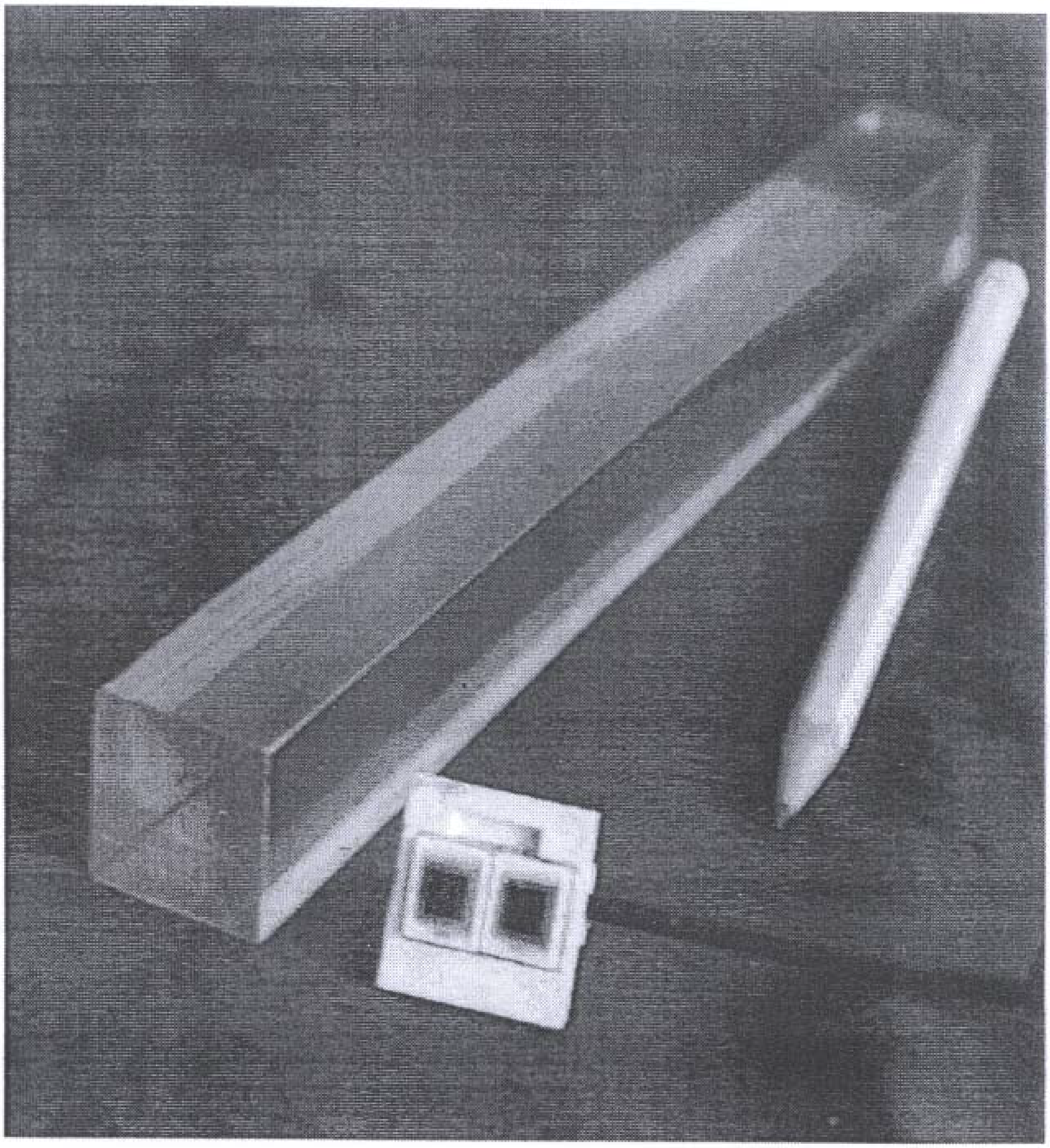
- compact, thickness < 2 mm
- fast: 2-3 ns rise time
- high quantum efficiency: ≈ 80 %
- insensitive to pickup (coherent noise)
- insensitive to magnetic fields
- simple and reliable operation
- mass production potential
- small parameter spread
- high radiation resistance
- insensitive to particles passing the device

Historical (1992) comparison of the response to 80 GeV electrons of a lead tungstate crystal with a PIN diode (top) and an APD (bottom) readout. The tail to the right of the peak in the PIN diode spectrum is due to particles leaking out of the back of the crystal and passing through the diode (nuclear counter effect).



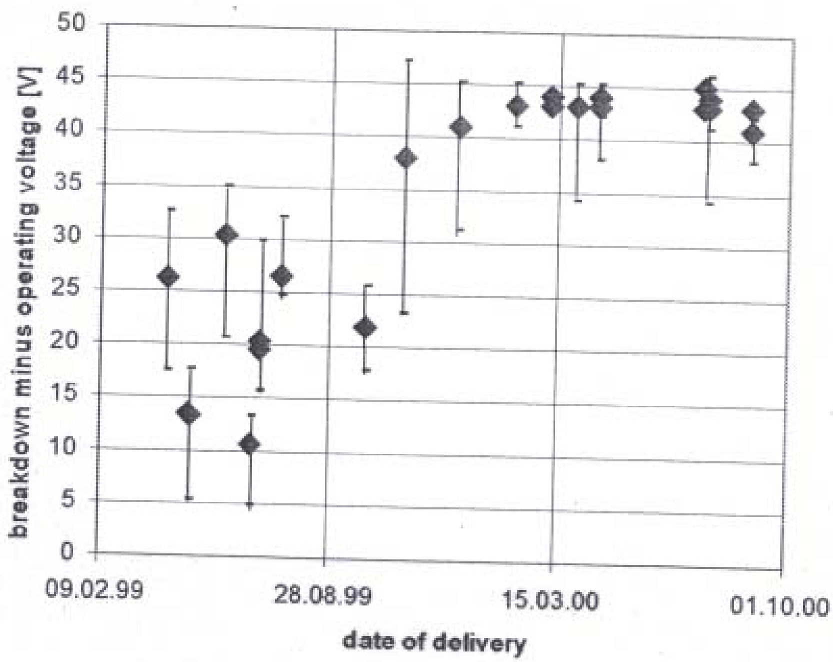
D. Renker, PSI

Two APDs are mounted in a plastic "capsule" ready for gluing onto a $PbWO_4$ crystal. Each APD has a 5x5 mm^2 sensitive area. The pencil indicates the dimensions.

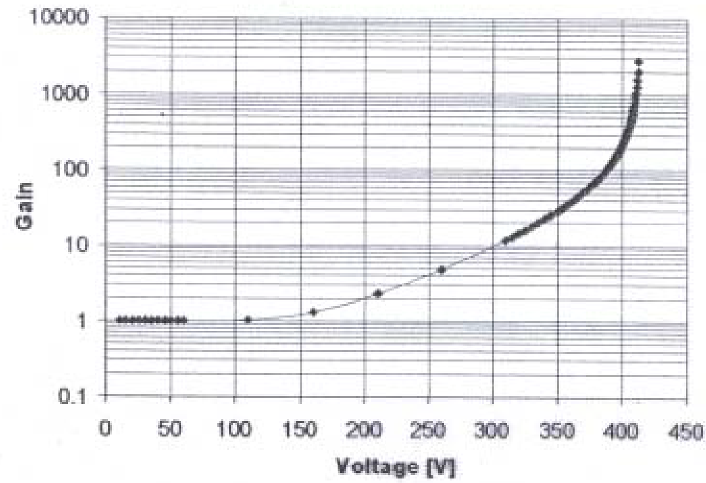


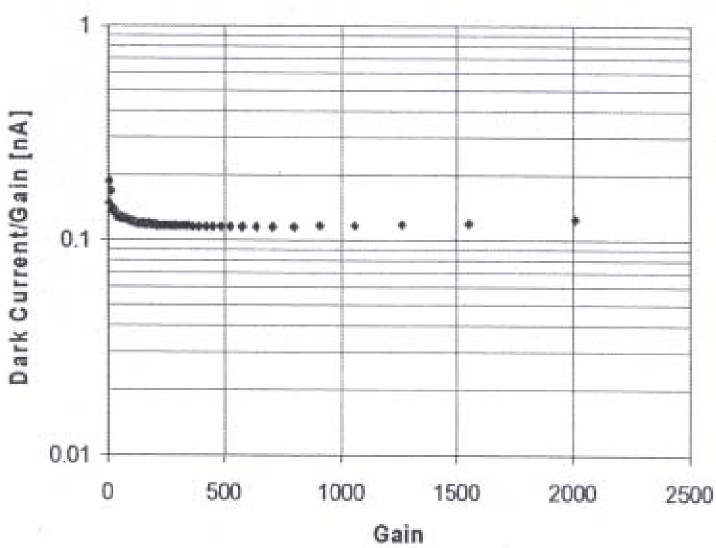
D. Renker, PSI

During the last two years the performance of APDs was improved steadily. The distance of the operating voltage for a gain of 50 to the breakdown voltage increased to more than 40 V and is now stable with a small spread.

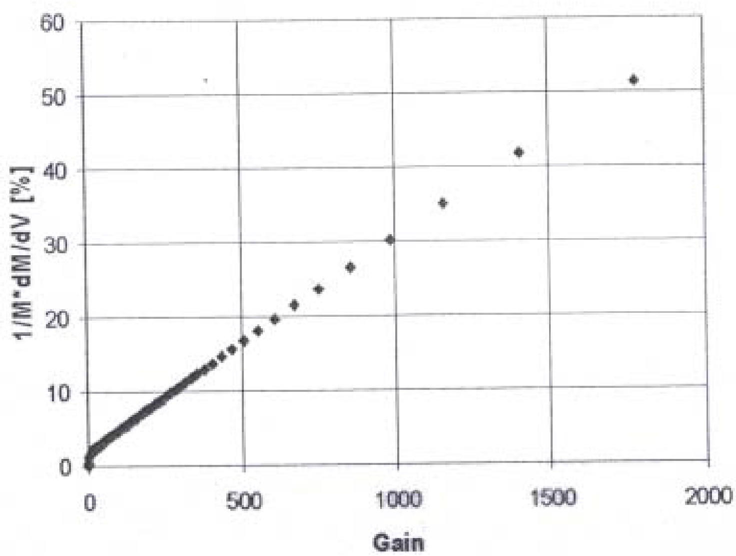


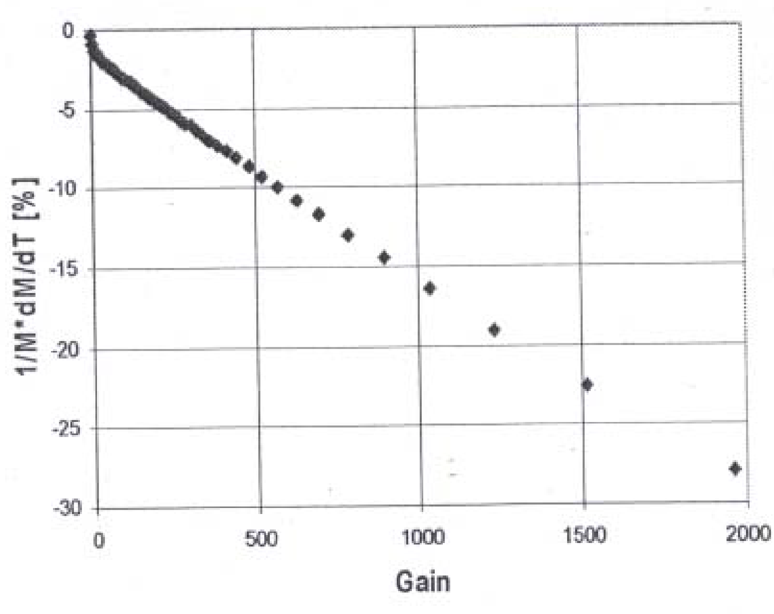
Recent APDs can be operated at a gain as high as 2000. The dark current typically is 5 to 10 nA at a gain of 50 and there are no anormalies at high gain: the value of dark current divided by gain is a constant.



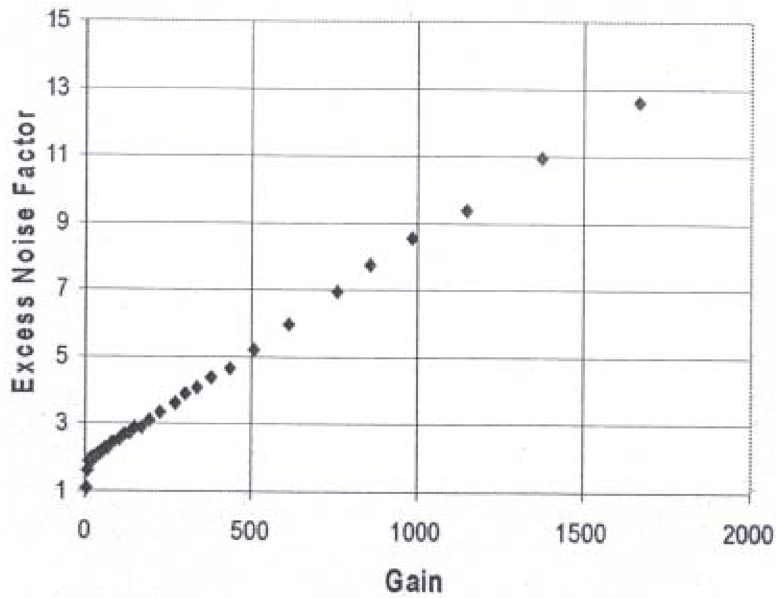


The gain is a steep function of the bias voltage. At a gain of 50 (the value chosen by CMS) dM/dV*1/M is 3 %. Due to phonon interactions the gain decreases with temperature by 2.2 %/°C, a value which is almost identical to the temperature coefficient of $PbWO_4$ (-2 %/°C at 20°C).

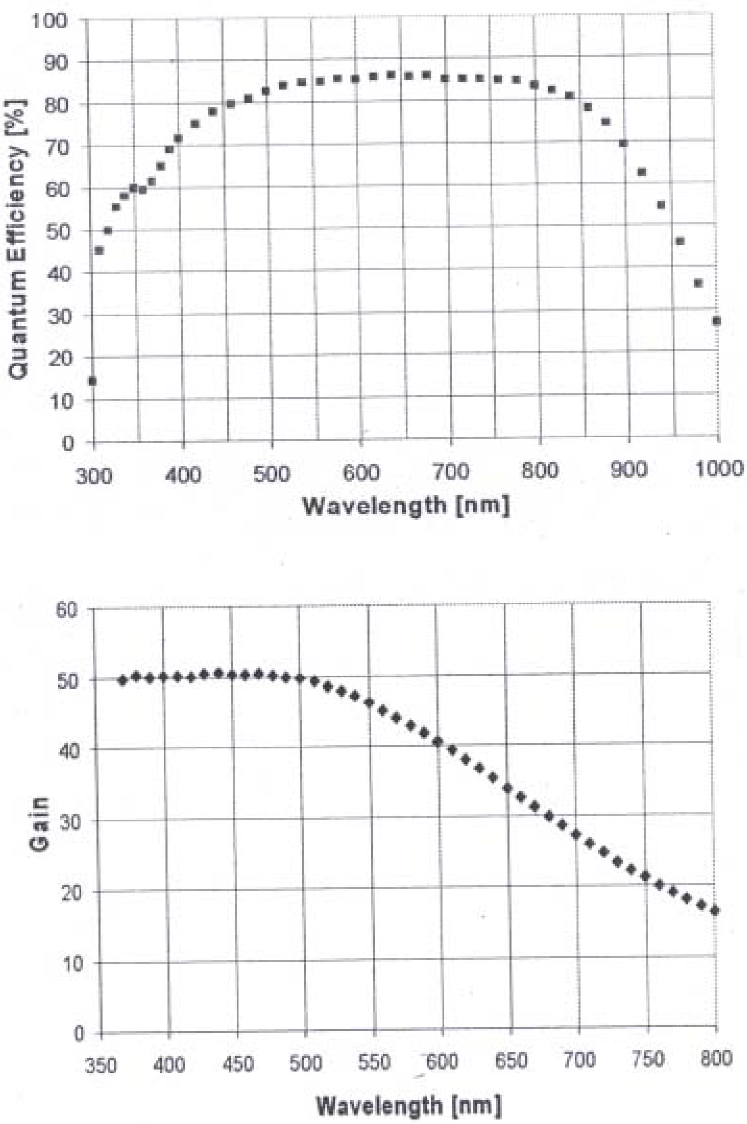




The excess noise factor at low gain is close to the theoretical limit. At a gain of 50 its value is 2.

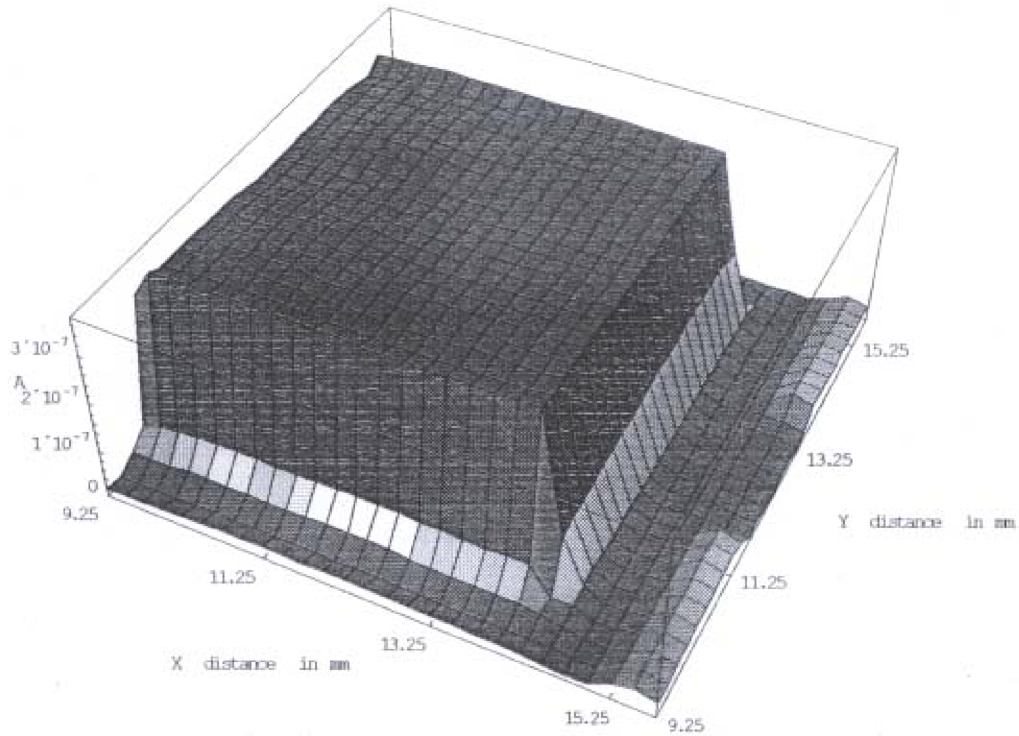


The quantum efficiencies of all APDs delivered in 2000 have values between 75 and 80 % at 420 nm, the emission of $PbWO_4$. No change has been observed after irradiation. Due to the thin (~5 µm) layer of p-silicon in front of the amplification region the gain drops for light with wavelength longer than 500 nm.

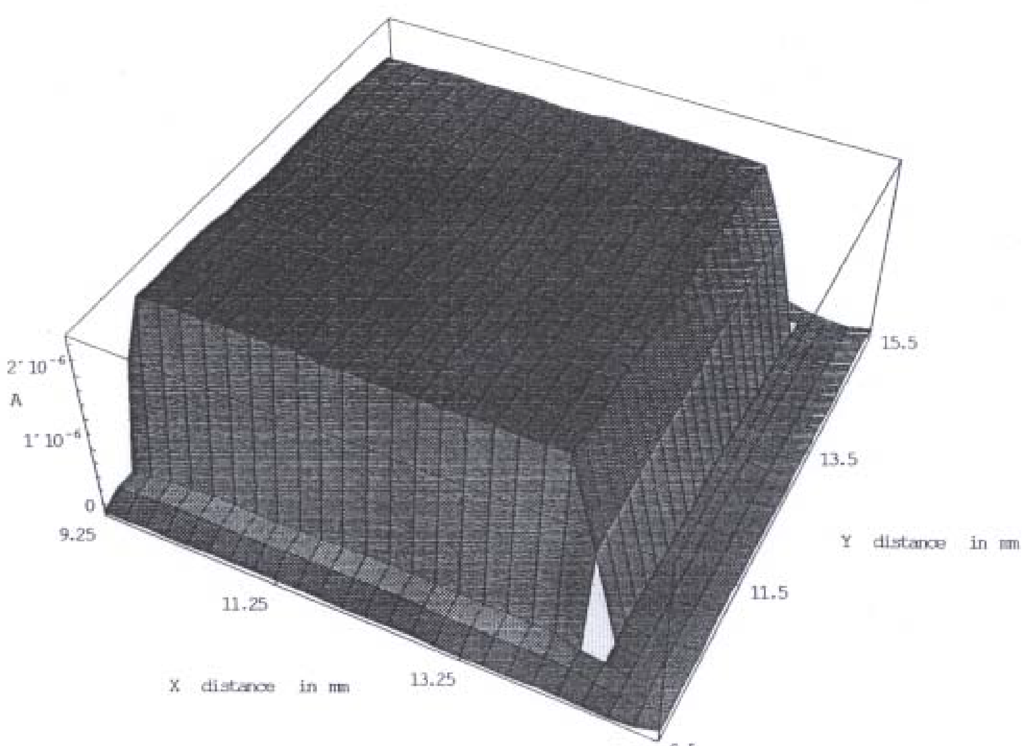


Uniformity Plots

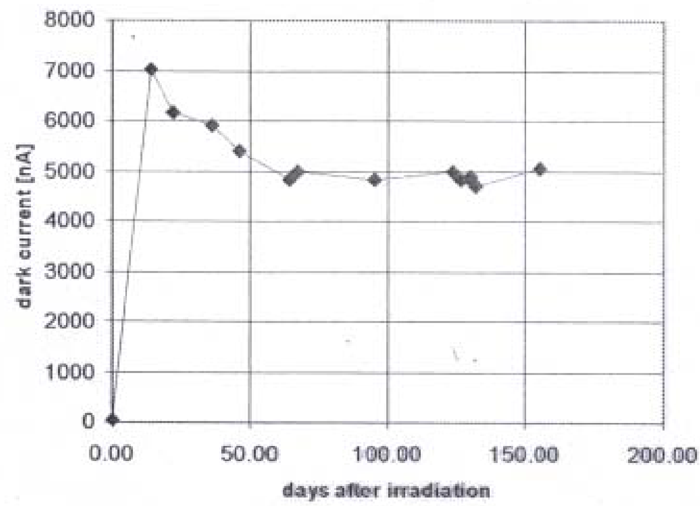
420 nm

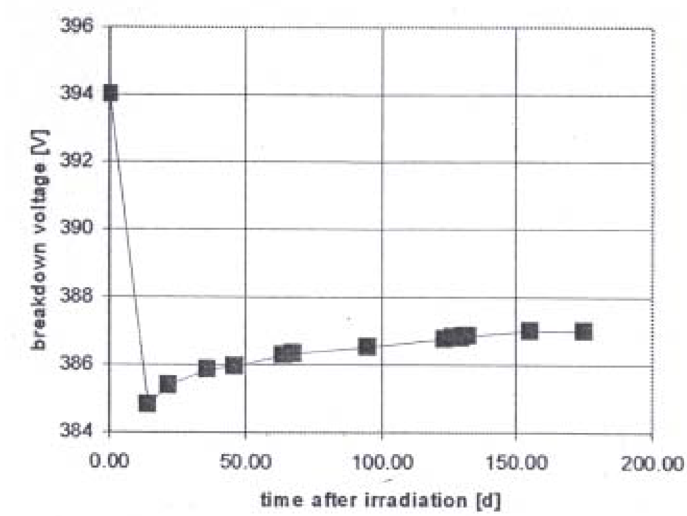


600 nm

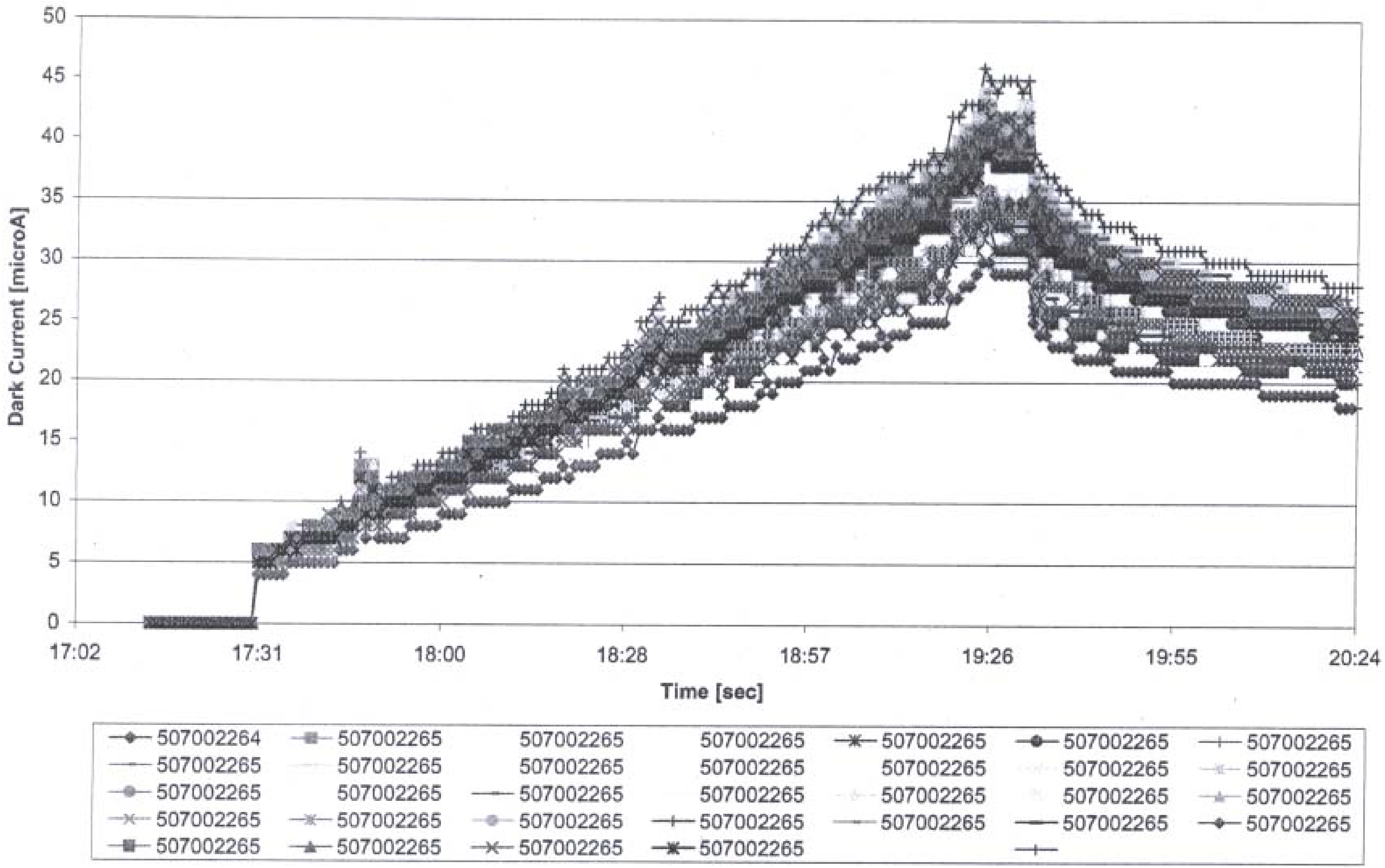


APDs have been irradiated with an equivalent of $2*10^{13}$ n/cm^2 (10 years of LHC running) and were then kept at 18 °C. After 150 days the dark current stabilized at 5 μA and the reduction of the breakdown voltage recovered slightly.





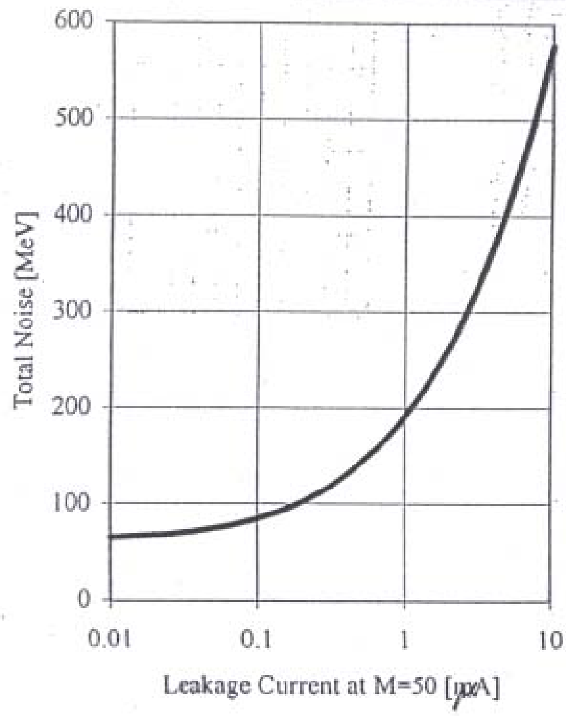
Proton Irradiation,Injector Lot5 (March 2000)



old_lot_5_cur.xls

26.09.2000

Noise (120 pF APD + 2 TeV Preamp)
(APD Leakage Current ≠ "0")



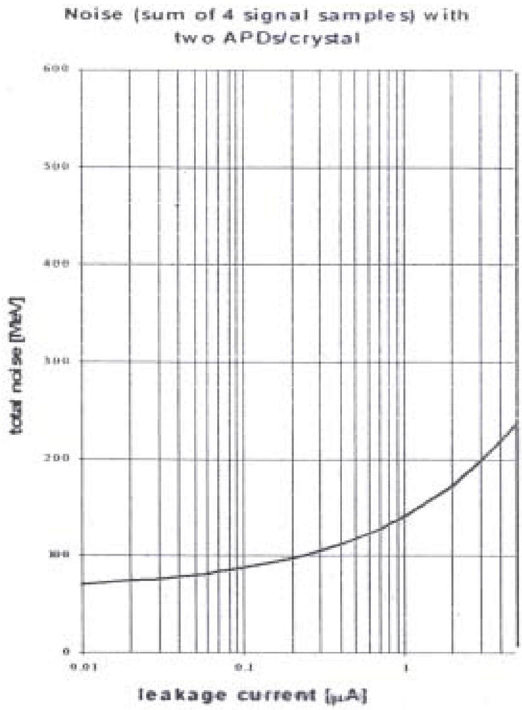
2 p.e. / MeV
1 pedestal pre-sample
Add 4 signal samples

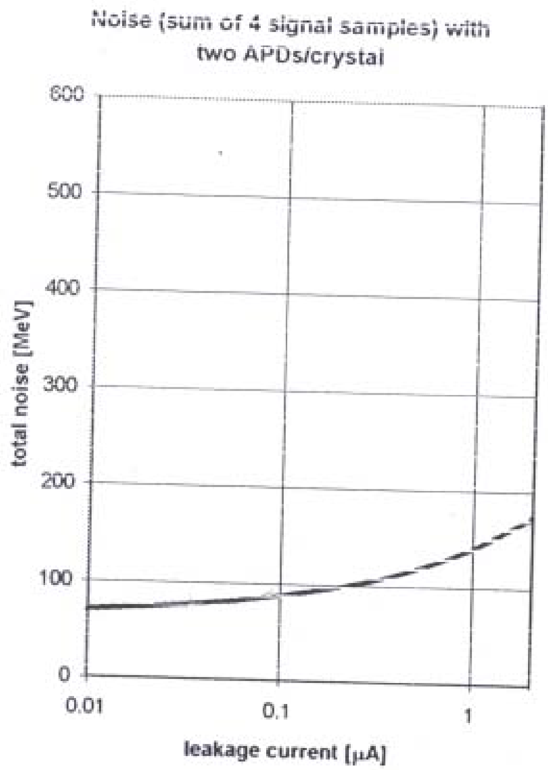
α (diffi
T (T"2"
t (e $^{-t/\tau}$)

Excess Noise Factor
~ at theoretical minimum

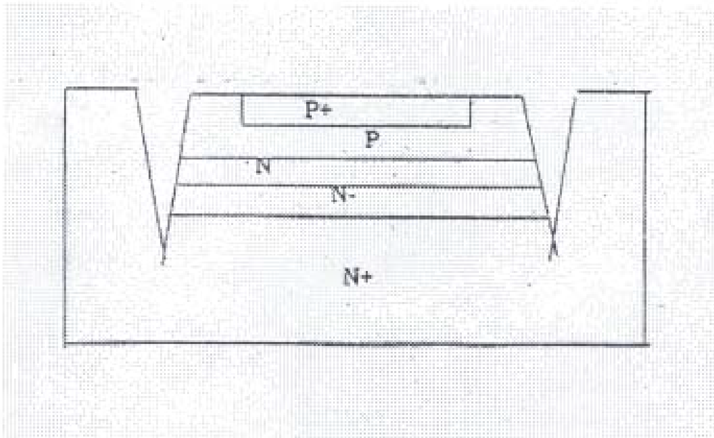
$$Noise \sim \frac{\sqrt{F}\sqrt{I_L(T,t)}}{N_{pe}}$$

Light Yield
of crystal
⊕ area of APD
⊕ coupling ...


Noise (sum of 4 signal samples) with two APDs/crystal
600
500
400
300
200
100
0
total noise [MeV]
0.01
0.1
1
leakage current [μA]


Noise (sum of 4 signal samples) with
two APDs/crystal
total noise [MeV]
600
500
400
300
200
100
0
0.01
0.1
1
leakage current [μA]

Structure of the selected APD type



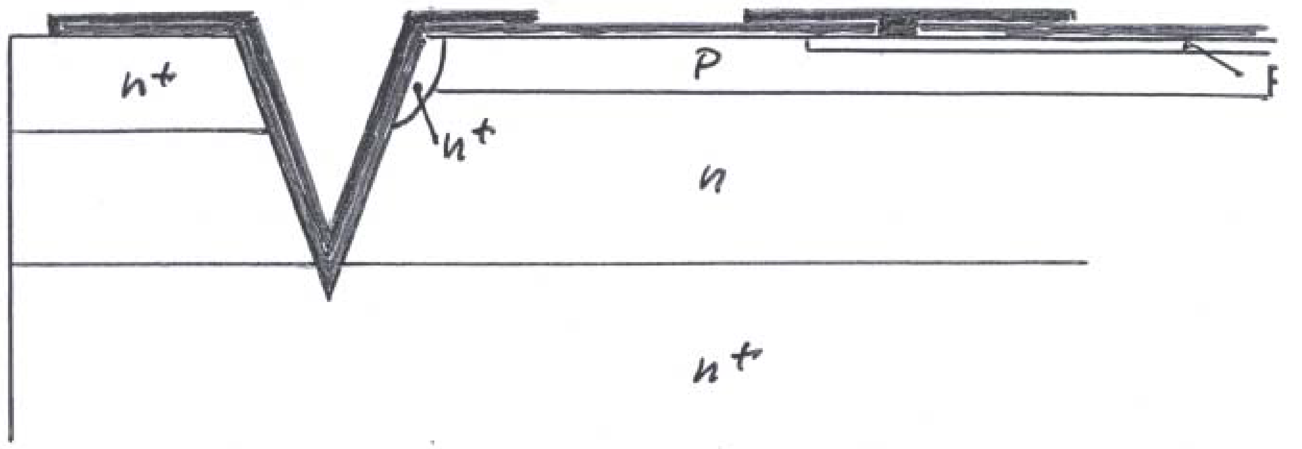
Parameters:

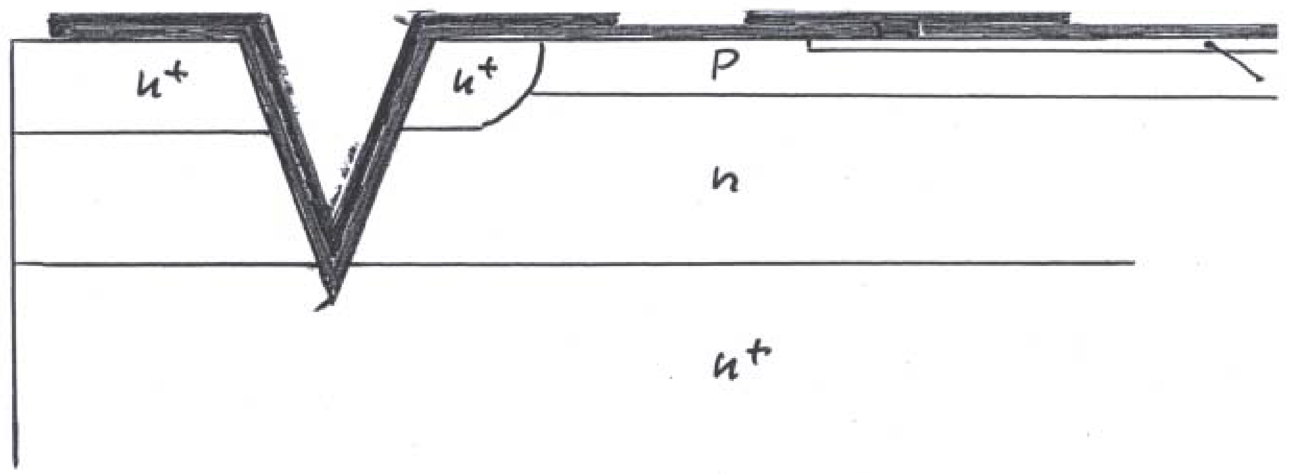
area:	5x5 mm^2
operating voltage:	≈ 330 V
capacity:	70 pF
serial resistance:	3 Ω
dark current:	< 10 nA
dM/dV*1/M:	3.3 % /V @ M=50
dM/dT*1/M:	2.2 % /°C @ M=50
quantum efficiency:	70 % @ 420 nm

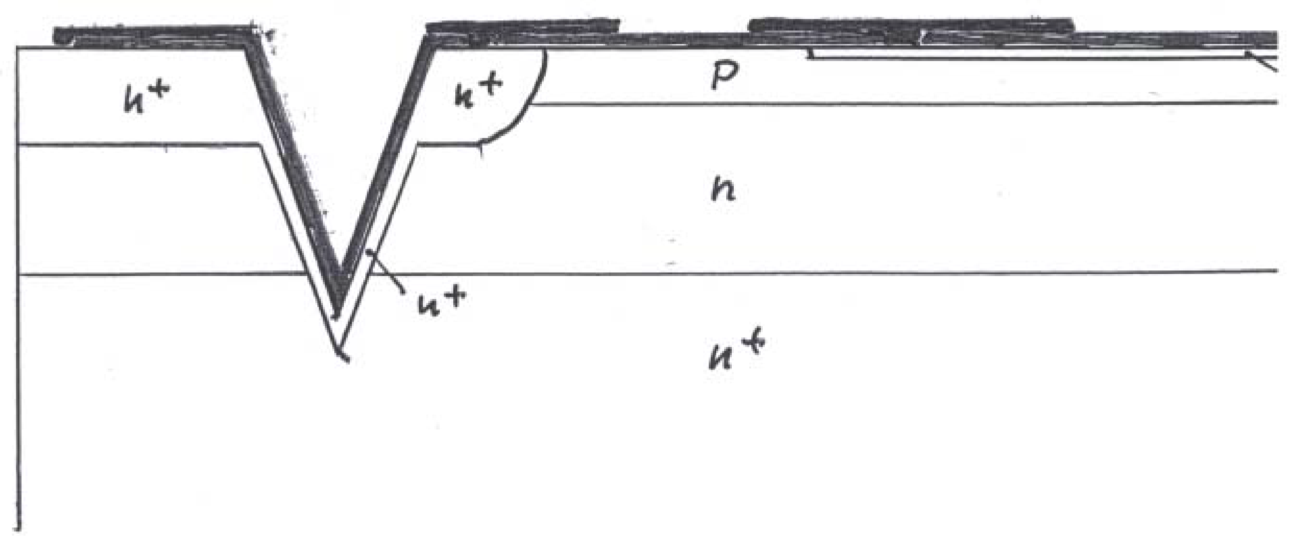
Hamamatsu APDs are produced by epitaxial growth on low resistivity N+ silicon, ion implantation and diffusion.

This type has a groove, which is some 30 micron deep and wide, to suppress the surface currents.

The layer of N- material was introduced to reduce the capacitance.







Al

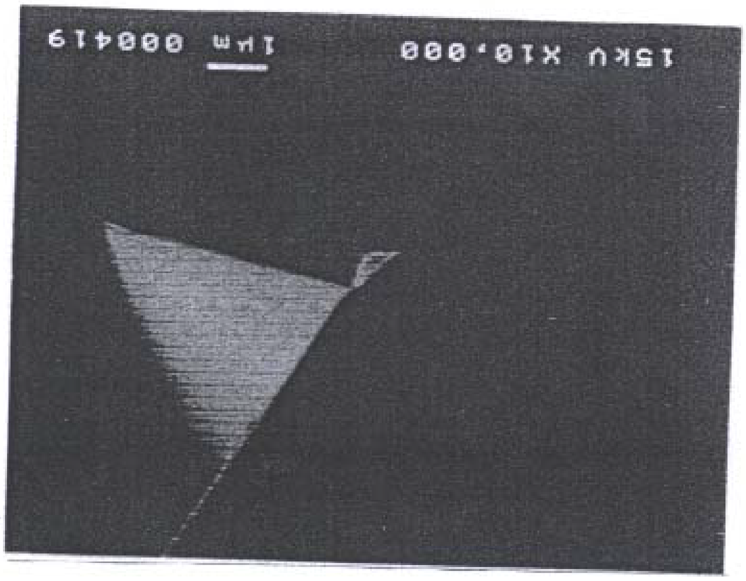


写真 4

拡大図

Al除去後

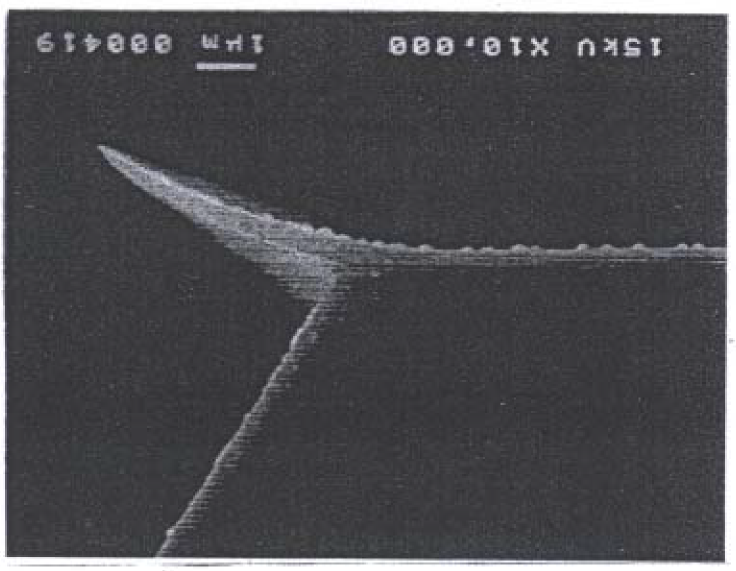


写真 5

拡大図

Al除去後

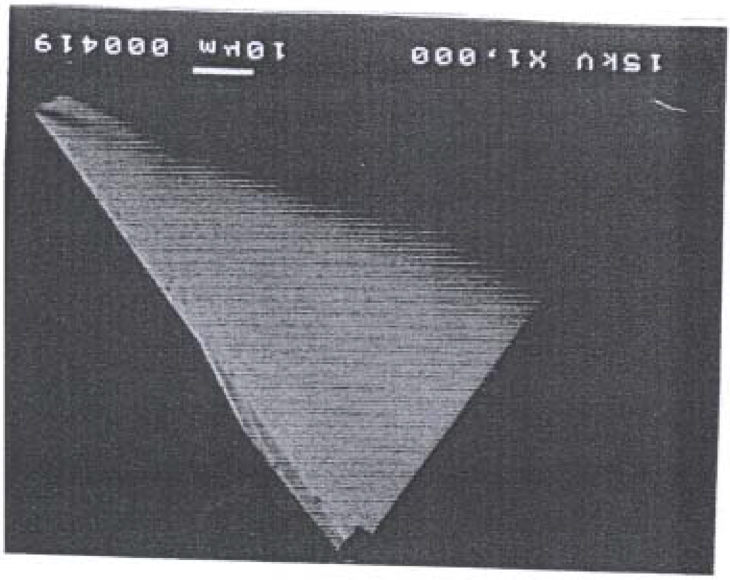


写真 1

V溝全体図

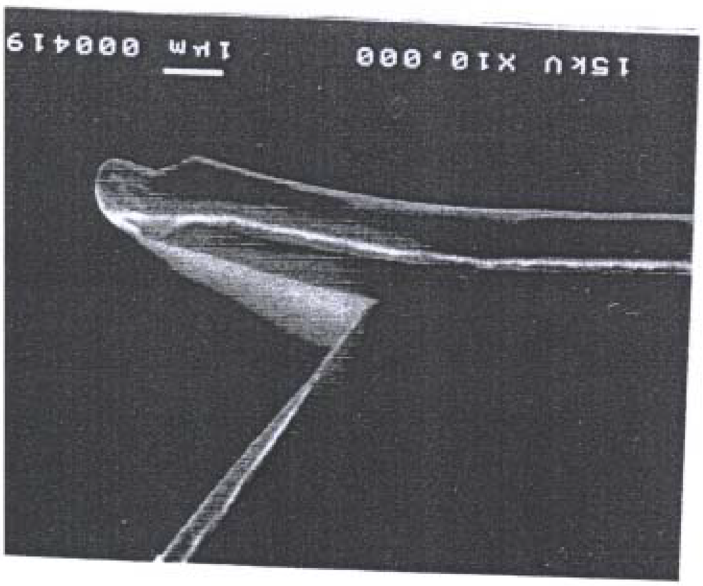
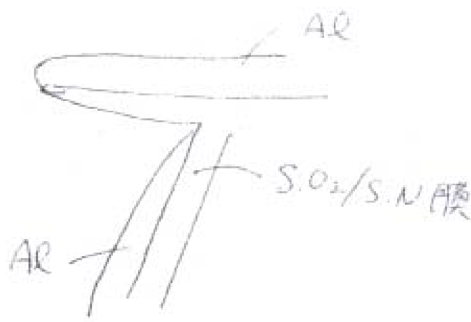


写真 2　拡大図



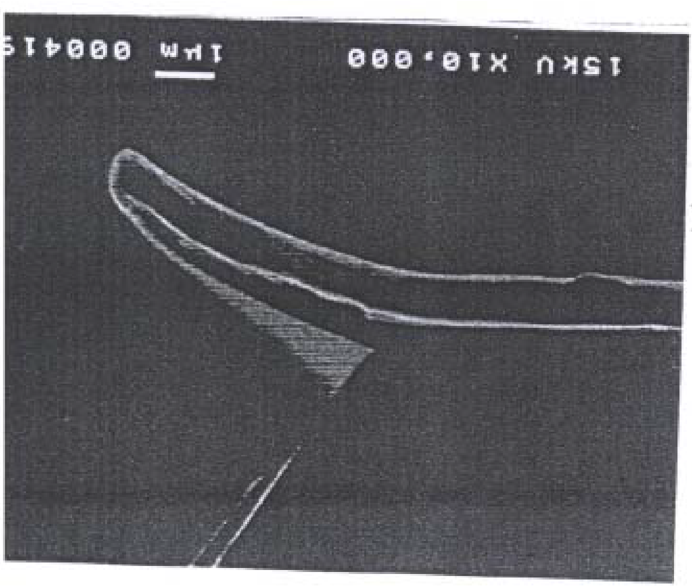
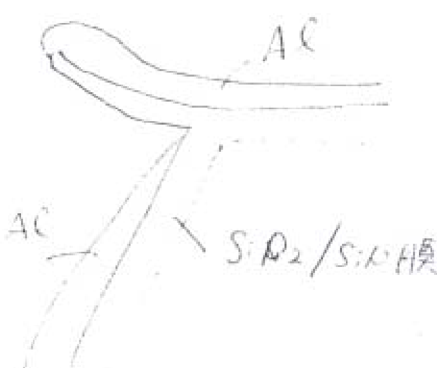
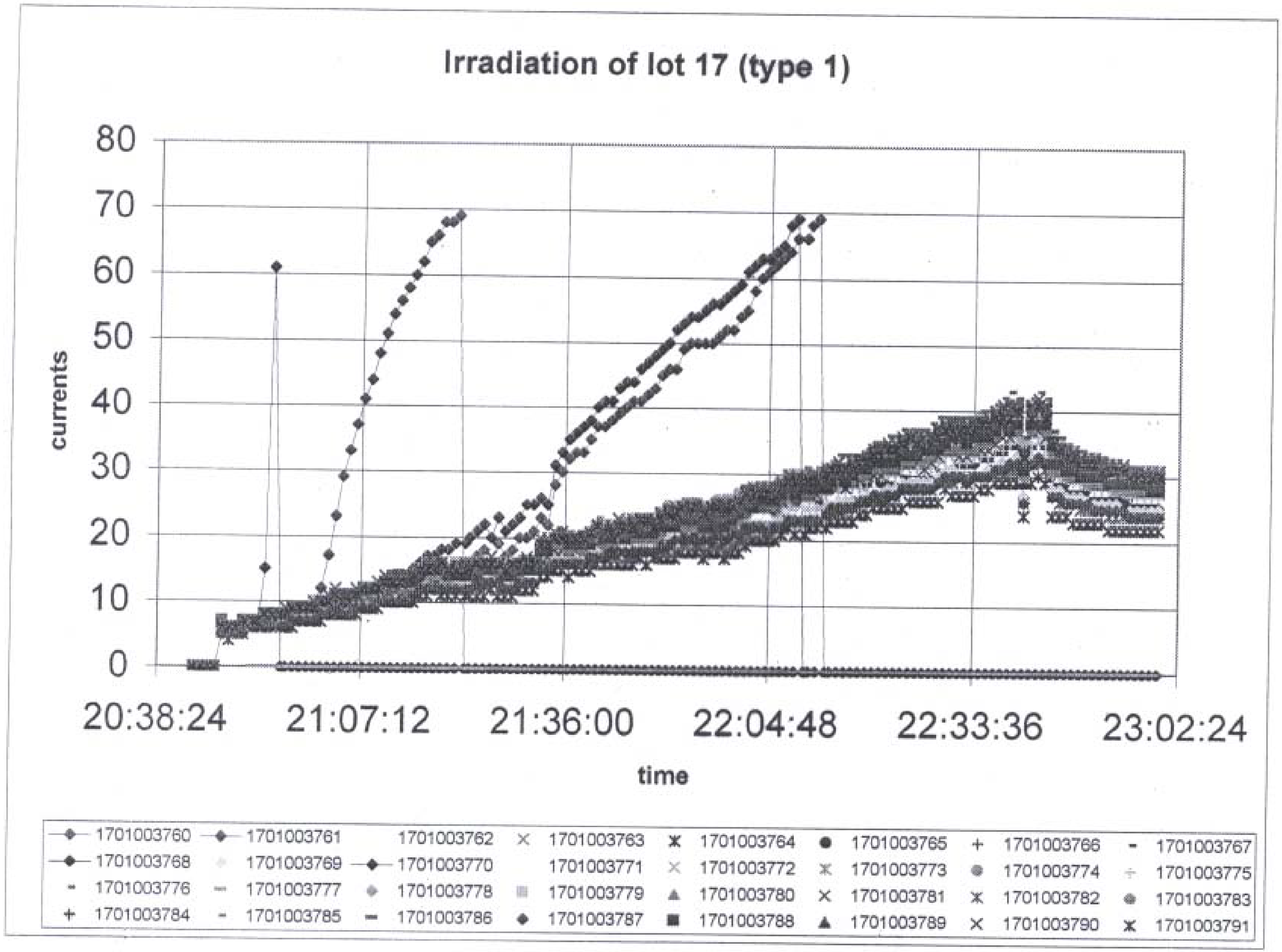


写真 3　拡大図




Irradiation of lot 17 (type 1)
currents
time
80
70
60
50
40
30
20
10
0
20:38:24
21:07:12
21:36:00
22:04:48
22:33:36
23:02:24
1701003760
1701003761
1701003762
1701003763
1701003764
1701003765
1701003766
1701003767
1701003768
1701003769
1701003770
1701003771
1701003772
1701003773
1701003774
1701003775
1701003776
1701003777
1701003778
1701003779
1701003780
1701003781
1701003782
1701003783
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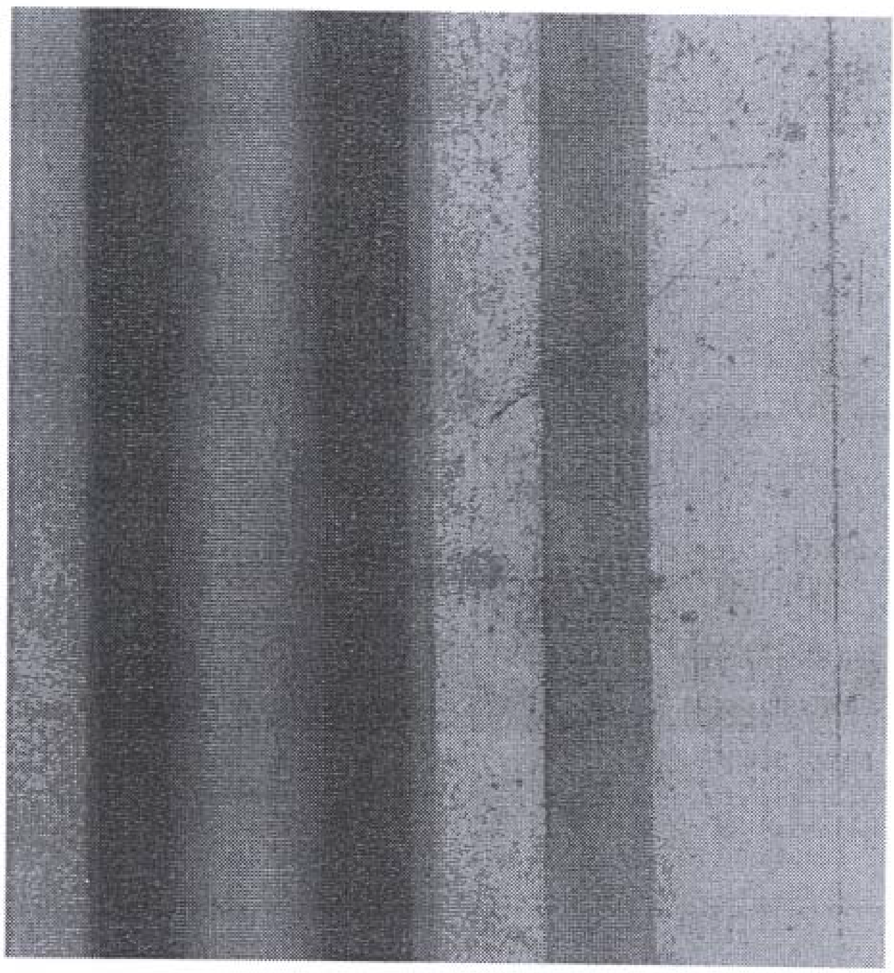
1701003789
1701003790
1701003791

Microscope view of the 100 μm wide groove and the 35 μm wide SiO_2 isolation (green). The aluminium layer between the groove and the SiO_2 isolation is on ground potential while the aluminium to the right of the isolation is connected to the bias voltage of some 350 V.



|← 100 μm →|

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