Mesh APD signal comparison between 980nm and 670nm Laser Diode triggered pulses

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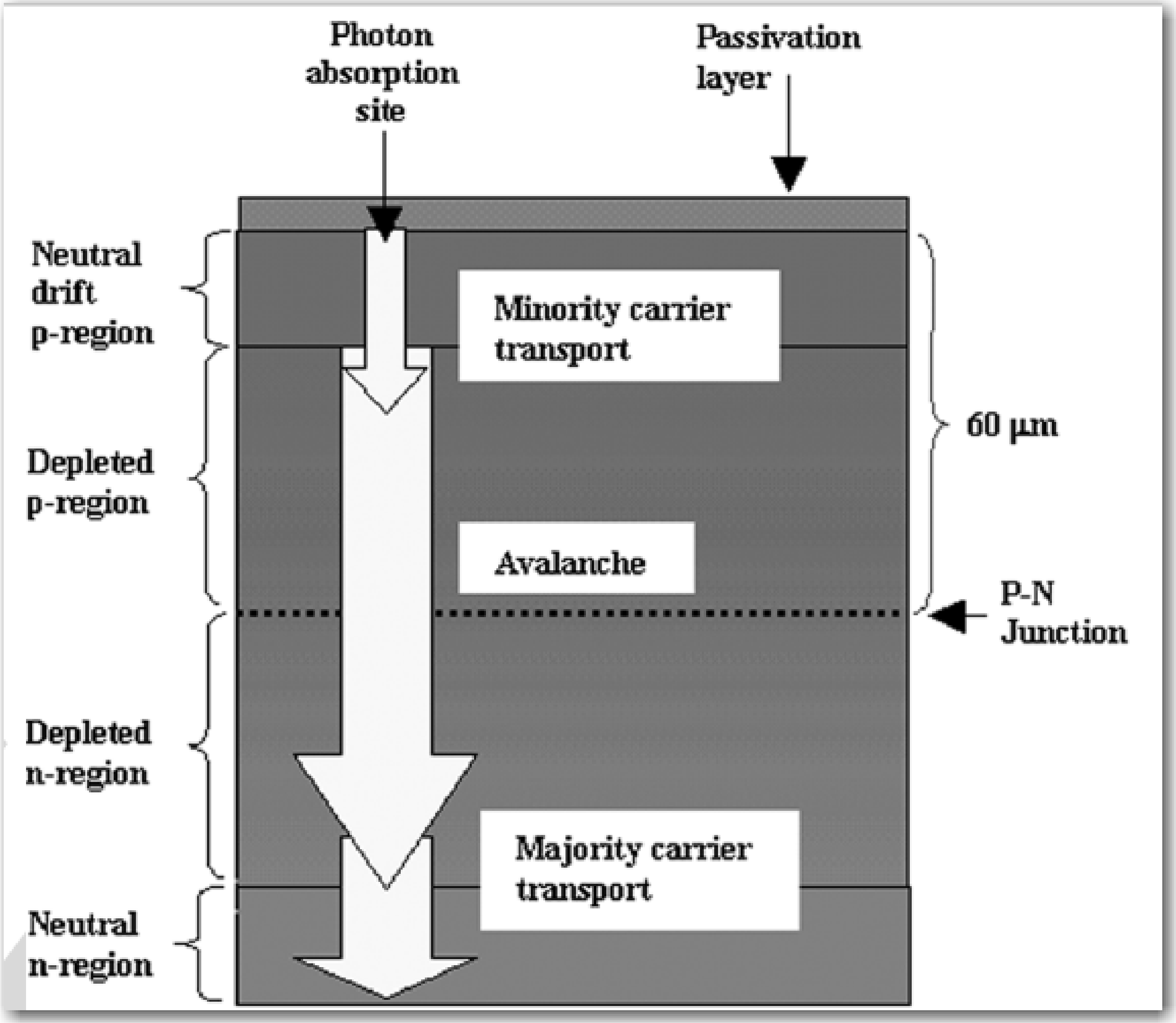
(2/18/2016)

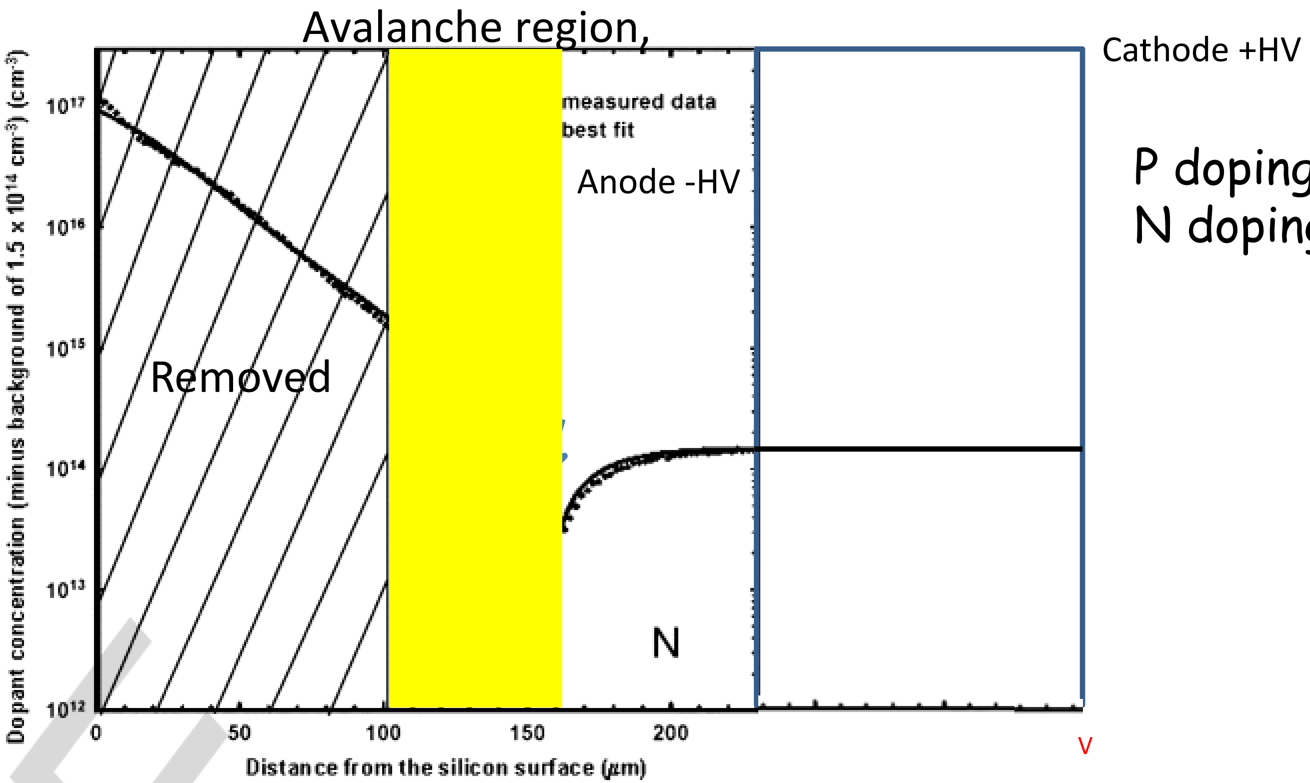
RMD deep diffused APD structure



Cross-sectional view of RMD deep diffused APD.

Reexamination of deep defused silicon avalanche photodiode gain and quantum efficiency
Mickel McClish, *et al.*
IEEE Transaction on Nuclear Science, Vol. 53, No. 5, Oct. 2006

RMD deep diffused APD structure in simulation



P doping: Al
N doping: Ga

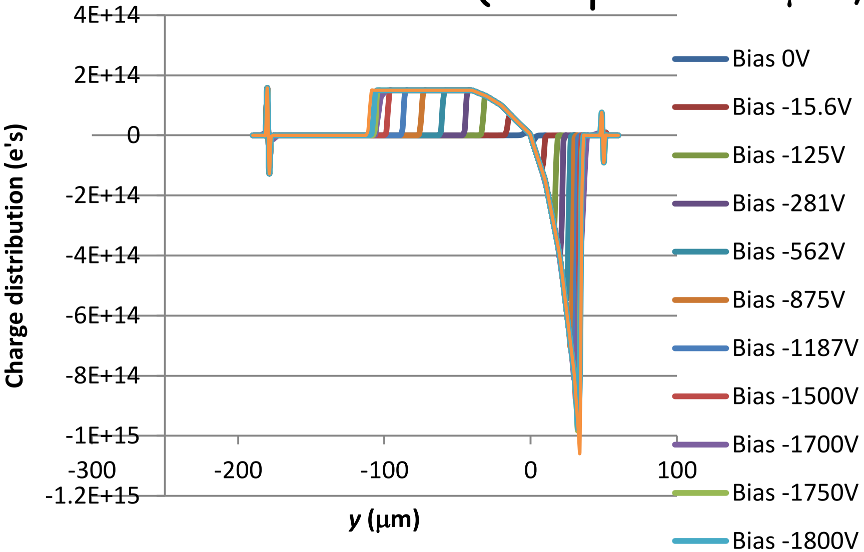
Fig. 4. A measured one-dimensional doping profile of a deep diffused Si wafer and a mathematical model fit to that data. The marked area indicates the amount of material etched away for detector fabrication. The P-N junction depth is 60 μm relative to the surface of the p-type material. The n-type region is really 190 μm, however the figure shows only $\sim 70\,\mu$m.

E

Calculation of E-field in the APD

(see my report "Simulation of RMD APD with VTCAD" on 10/29/2012)

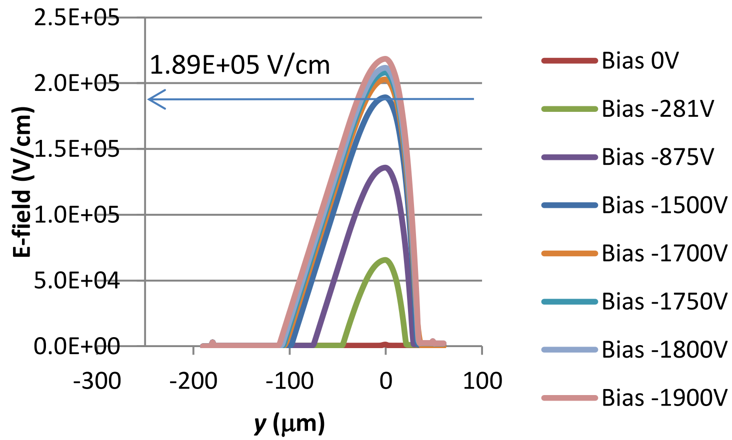
Extract the net charge distribution along with the central line of the APD model (*x* kept at 50 μm, *y* from -190 μm to 60 μm):



Net charge distribution along with the central line (*y* axis direction).

According to Poisson equation, we can use numerical integration of the charge density along with *y* axis to get *E*-field:

E_y(V/cm) = 1/ε∫ qdy, ε = 11.7 x 8.85 x 10^{-14} (F/cm),
q is the charge density (as shown on the left), integration from -190 μm to 60 μm.



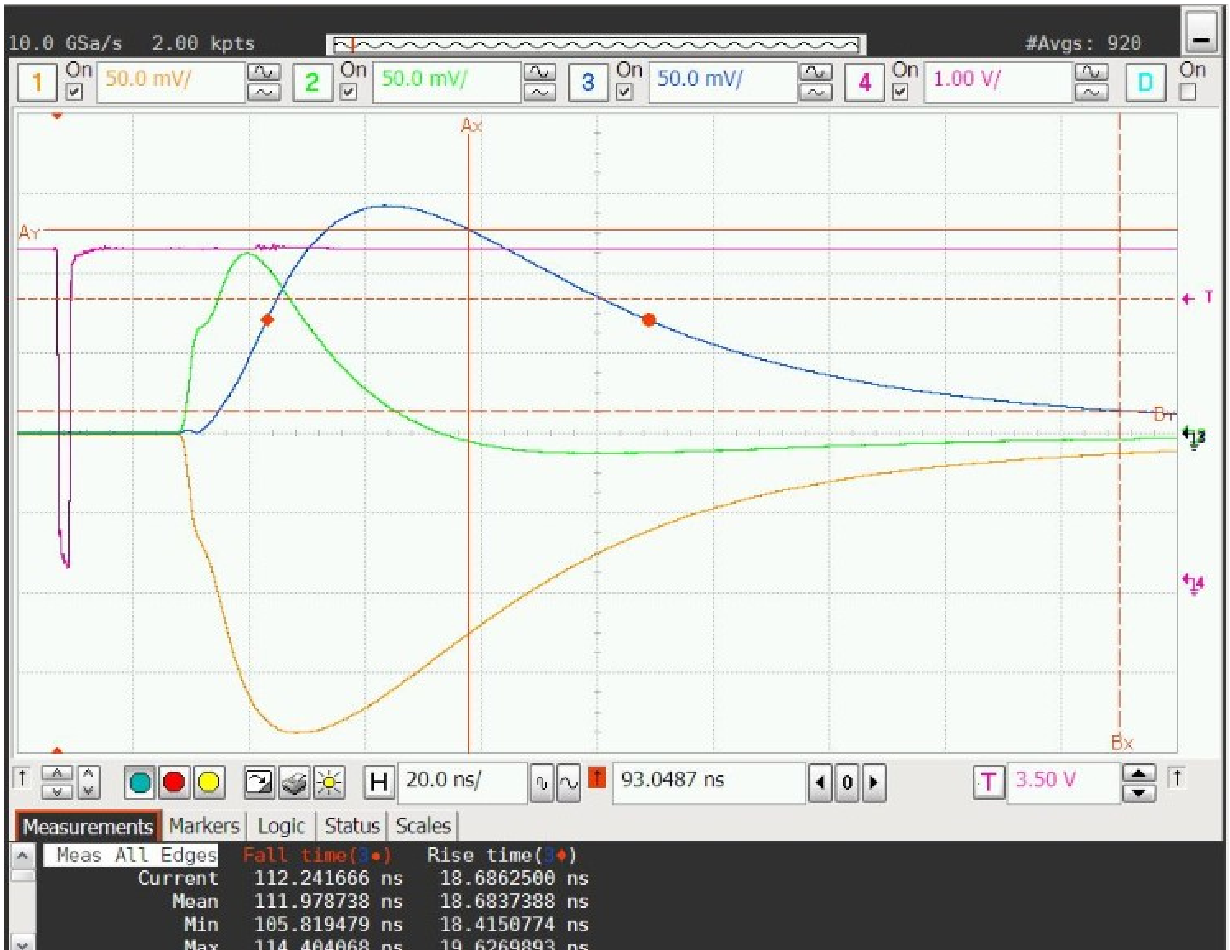
The maximum *E*-field for -1500V bias is ~189 kV/cm.

Test mesh APD with red laser diode (670nm)

HP pulser settings: Width = 1 ns, Vhigh = 4 V, Vlow = 0 V, Comp=Off
Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger; APD HV = -1800 V

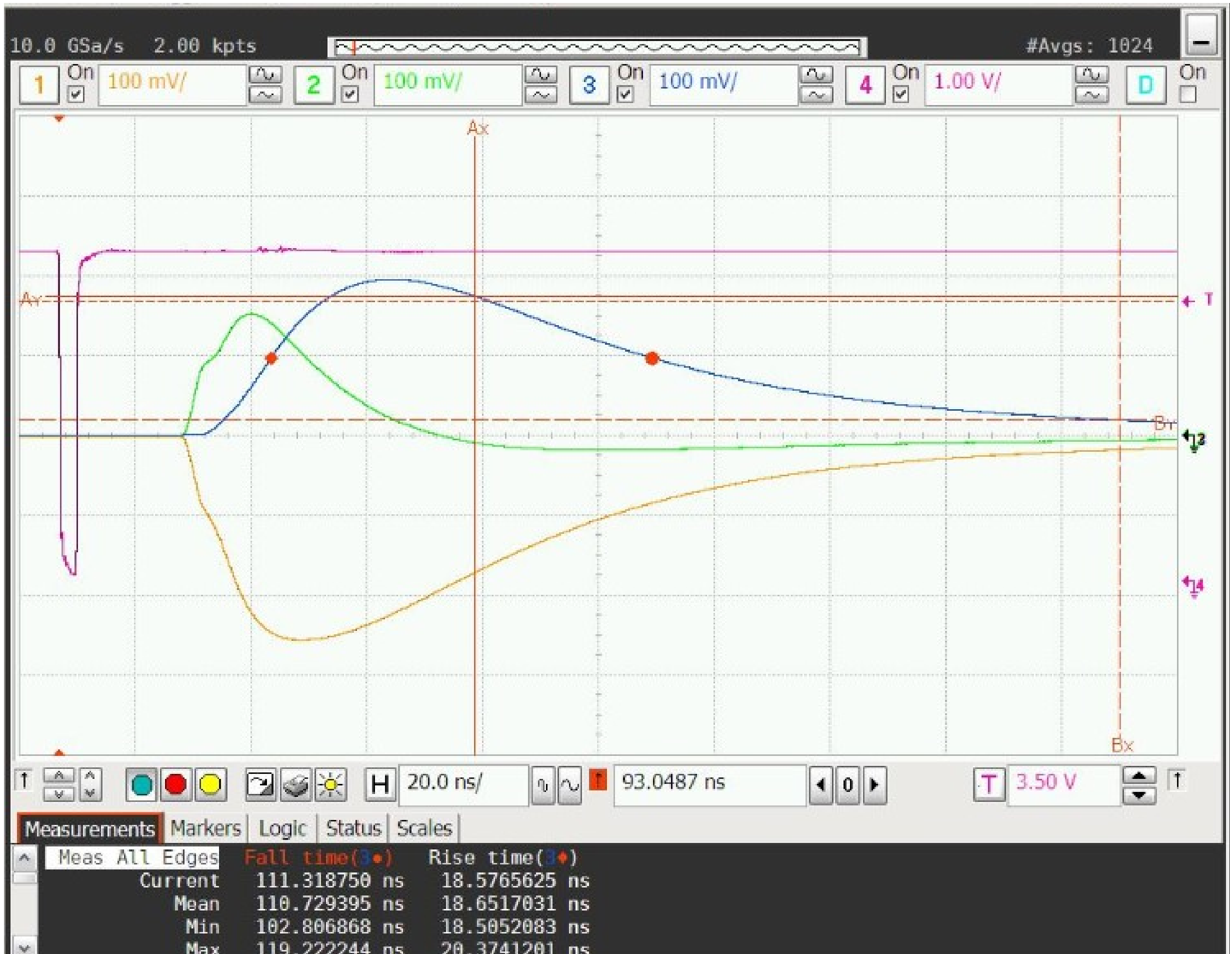
Test mesh APD with red laser diode (670nm)

HP pulser settings: Width = 2 ns, Vhigh = 4 V, Vlow = 0 V, Comp=Off Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger



Test mesh APD with red laser diode (670nm)

HP pulser settings: Width= 3 ns, Vhigh = 4 V, Vlow = 0 V,
Comp=Off Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger

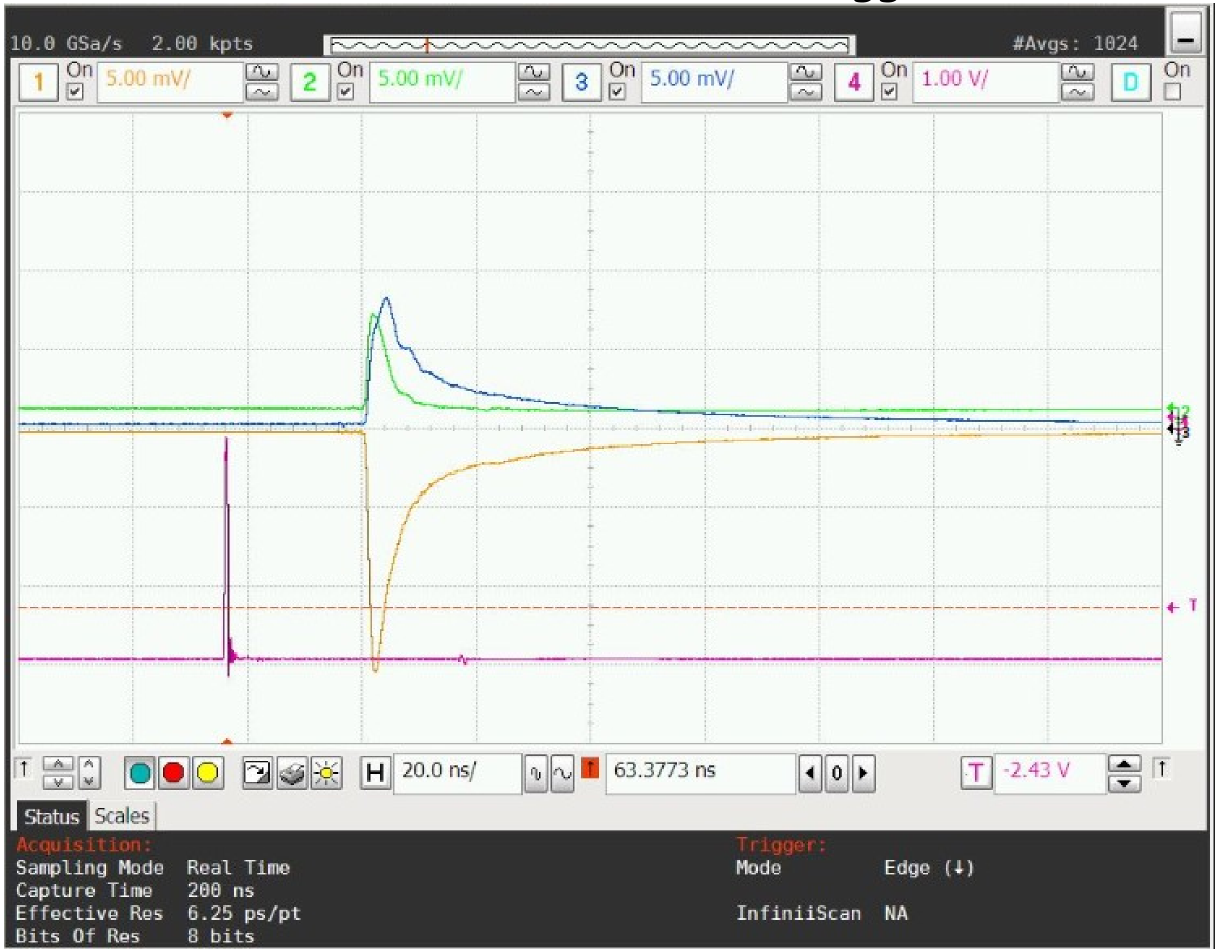


Test mesh APD with red laser diode (670nm)

HP pulser settings: Width= 4 ns, Vhigh = 4 V, Vlow = 0 V, Comp=Off Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger

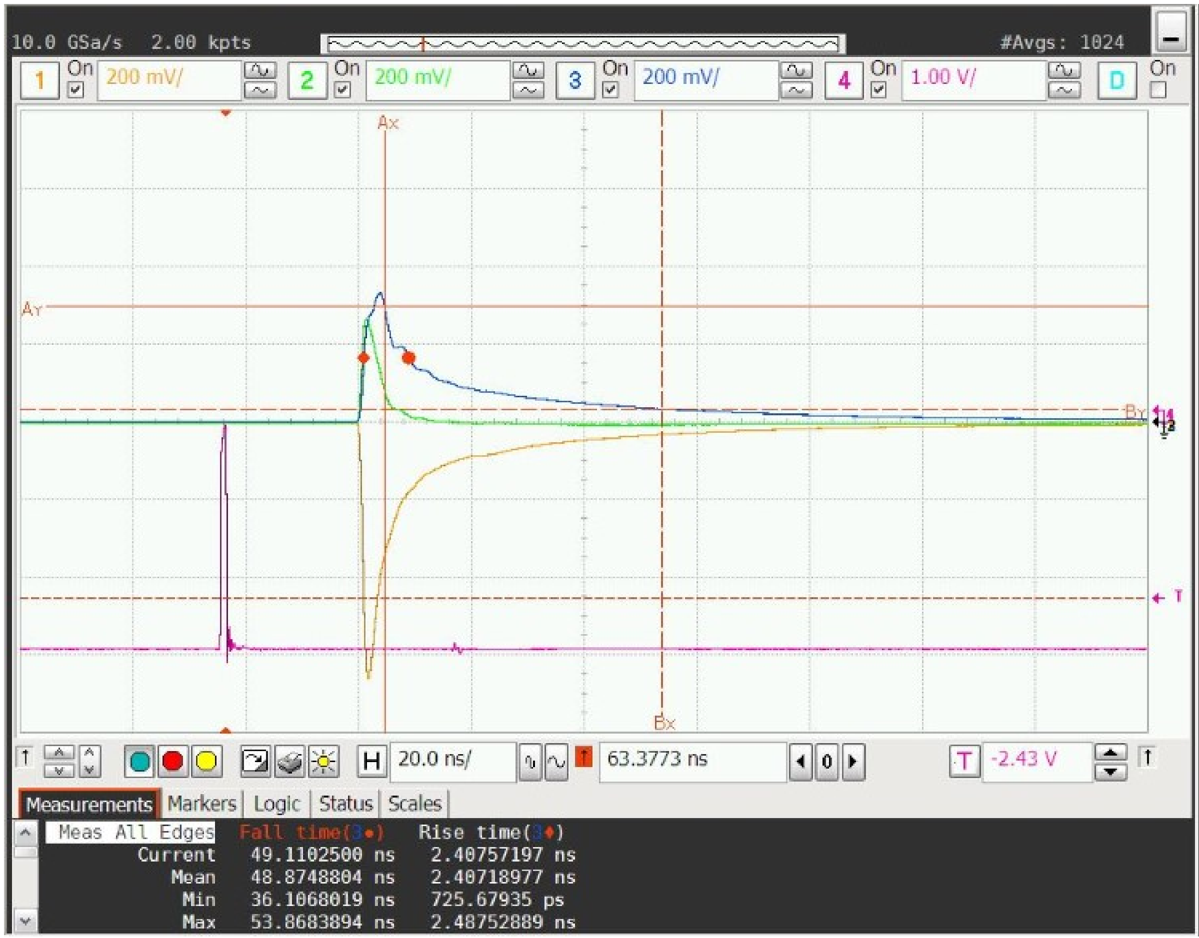
Test mesh APD with infrared laser diode (980nm)

HP pulser settings: Width= 0.7 n s, Vhigh = 3 V, Vlow = 0 V, Comp=Off
Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger; APD HV = -1800 V



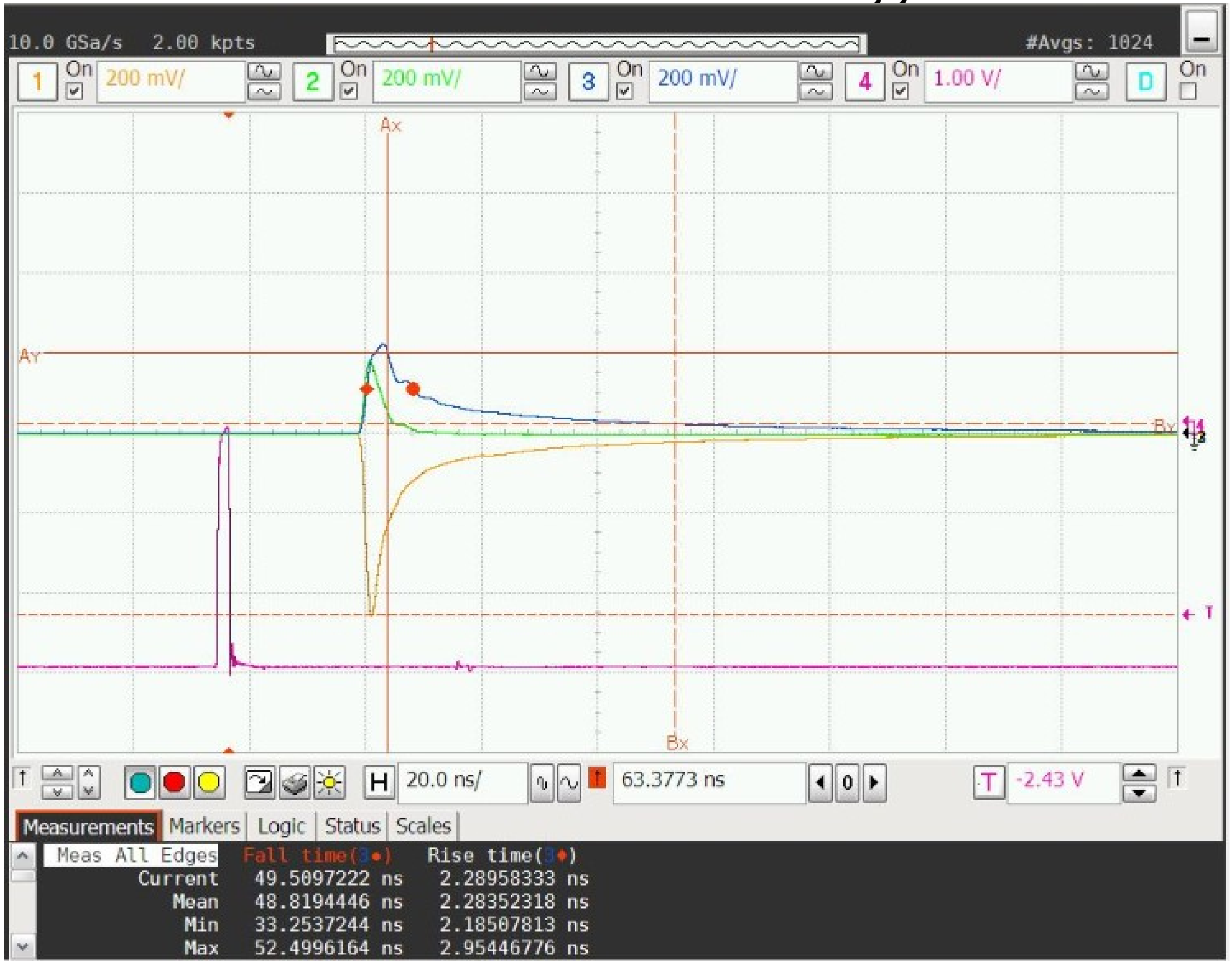
Test mesh APD with infrared laser diode (980nm)

HP pulser settings: Width= 1 ns, Vhigh = 3 V, Vlow = 0 V, Comp=Off
Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger; APD HV = -1800 V



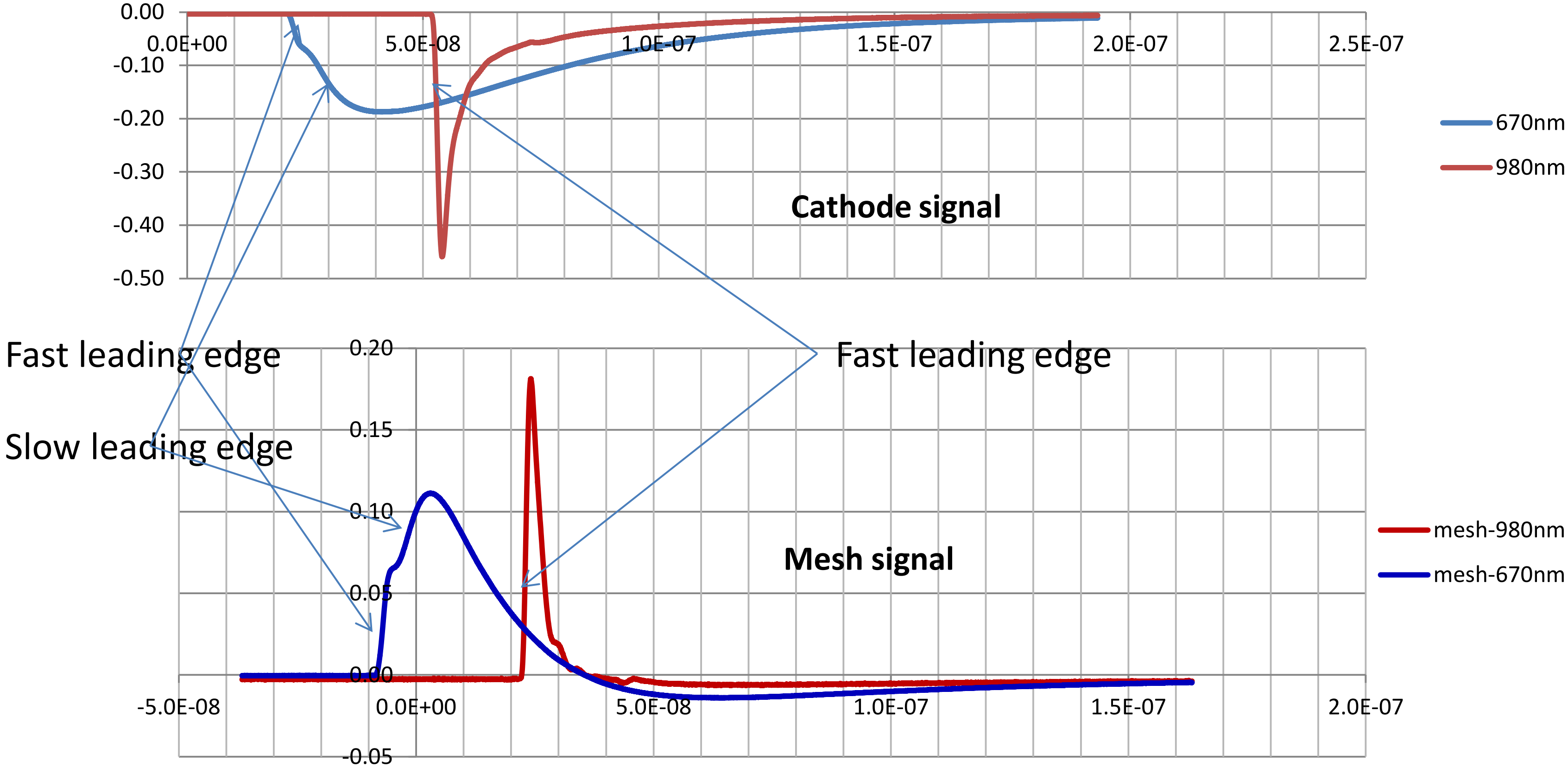
Test mesh APD with infrared laser diode (980nm)

HP pulser settings: Width = 2 ns, Vhigh = 3 V, Vlow = 0 V, Comp=Off
Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger; APD HV = -1700 V



Comparison between 670nm and 980nm

HP pulser settings: Width = 2 ns

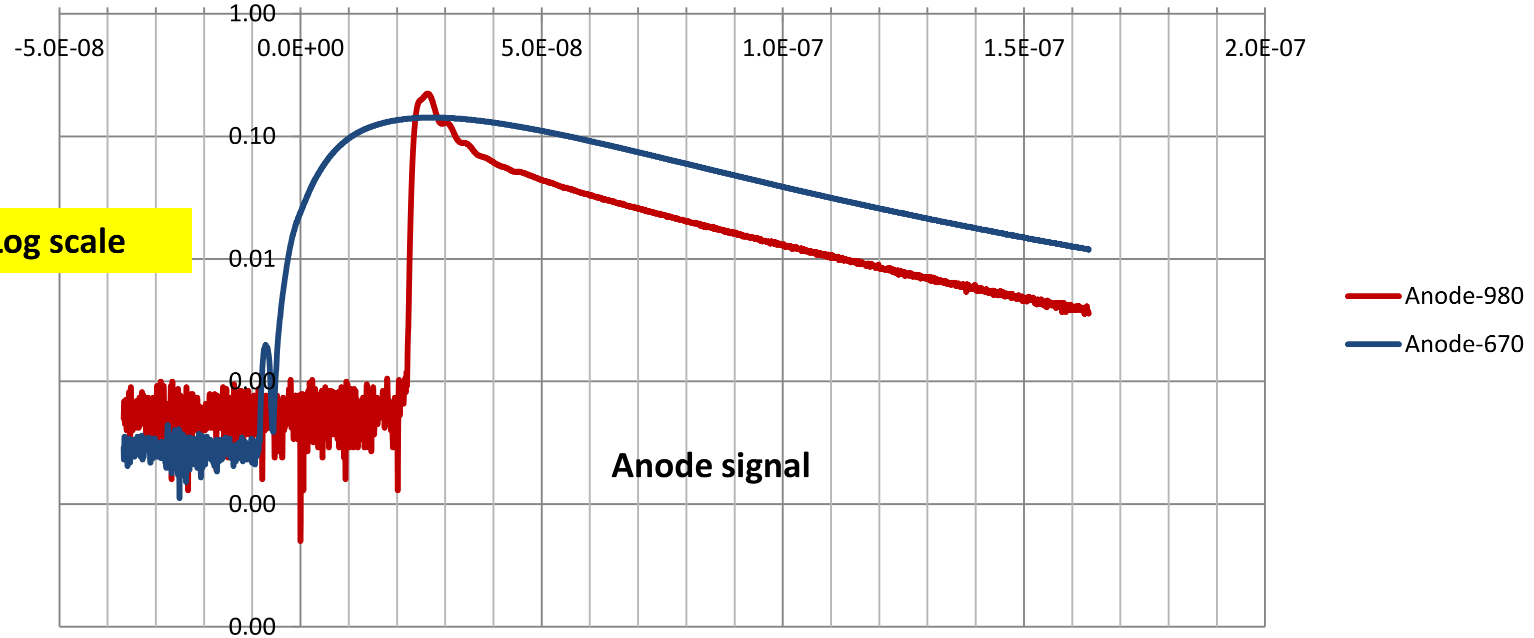


The very first part of the rise edges of 670nm signal is fast, similar to 980nm signal, then followed by slower and broader signal.

Comparison between 670nm and 980nm

HP pulser settings: Width = 2 ns

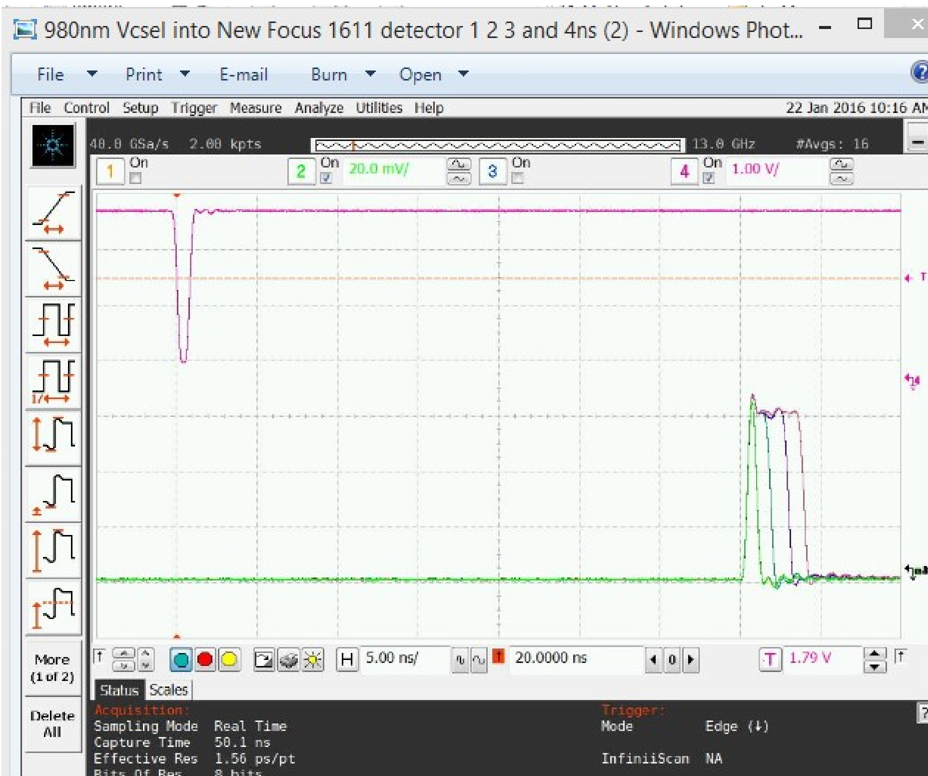
Log scale

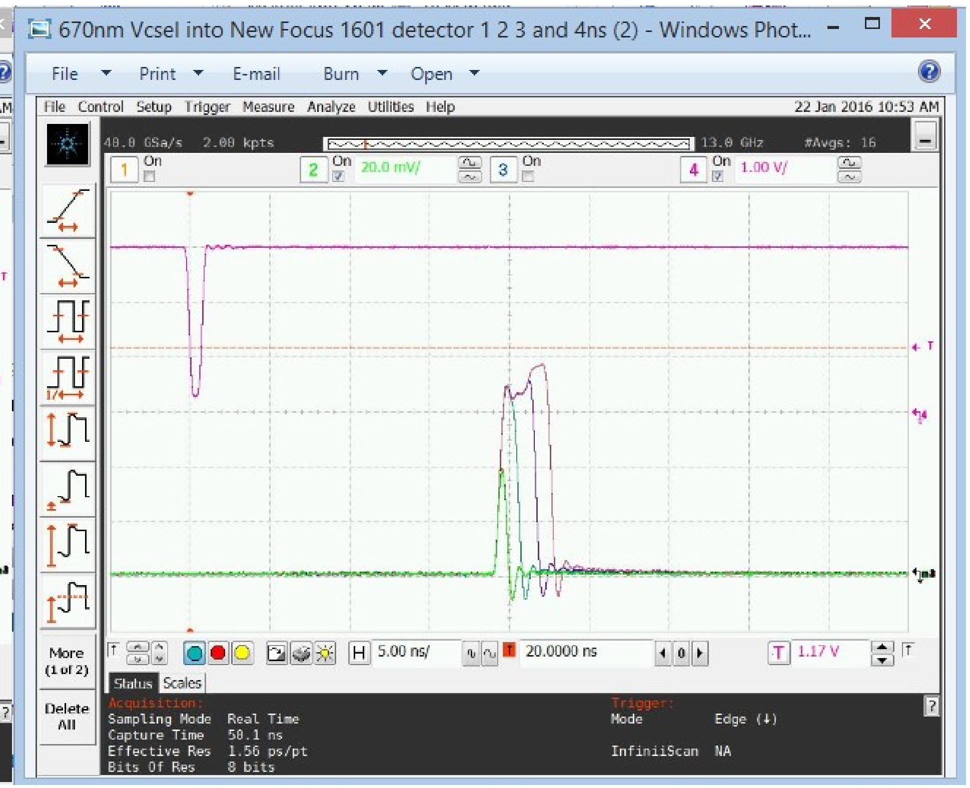


For anode signal we don't see the fast leading edge, only slow rising edge!

The light pulse of 670nm and 980nm Vcsel L.D.

Use fast photodiode to measure the light pulse shape to verify that they are similar for 670nm and 980nm L.D. cases, so the quite different APD signals we saw are due to APD itself.



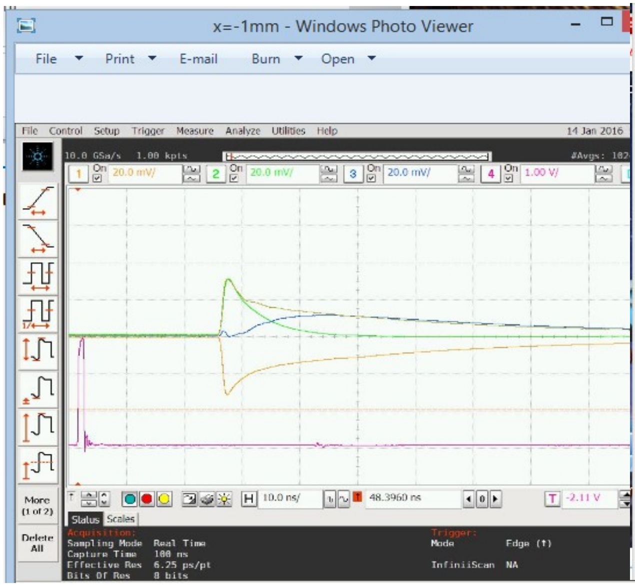


(Measured by Thomas Tsang @ BNL)

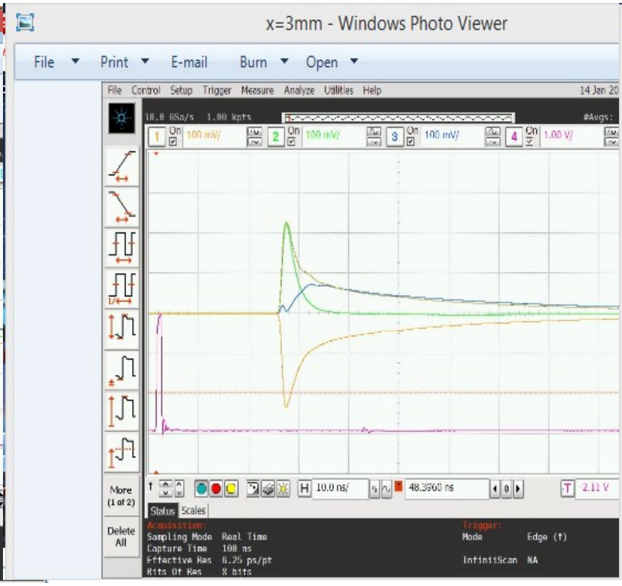
Scan mesh APD with 980nm LD

Scan the mesh APD active area with same 980nm laser light, x is on the horizontal direction, y is on the vertical direction. The grey waveform is the sum of mesh and anode signals. Without amplifier between APD and scope.

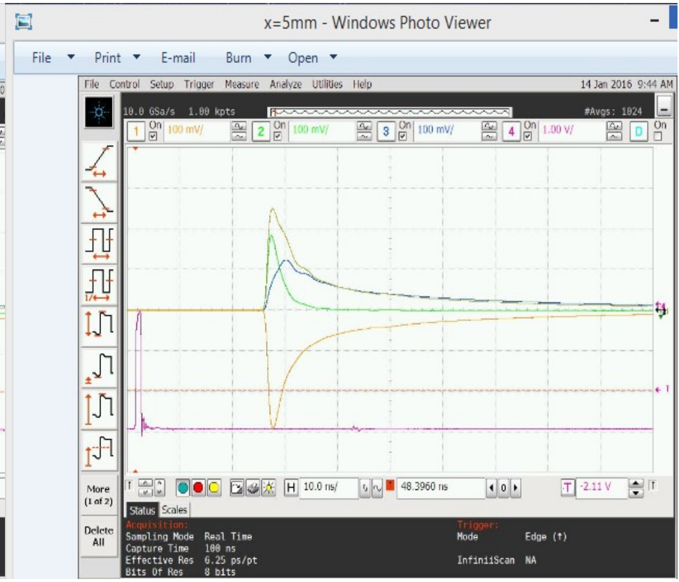
x = -1 mm, 20 mV/div.



x = 3 mm, 100 mV/div.



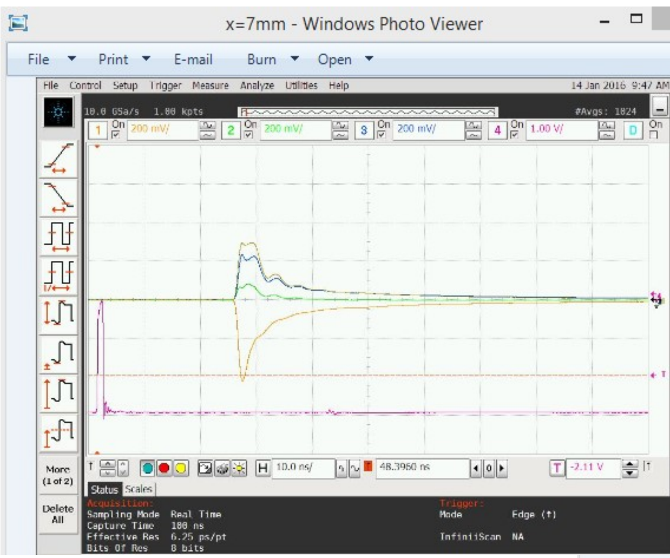
x = 5 mm, 100 mV/div.



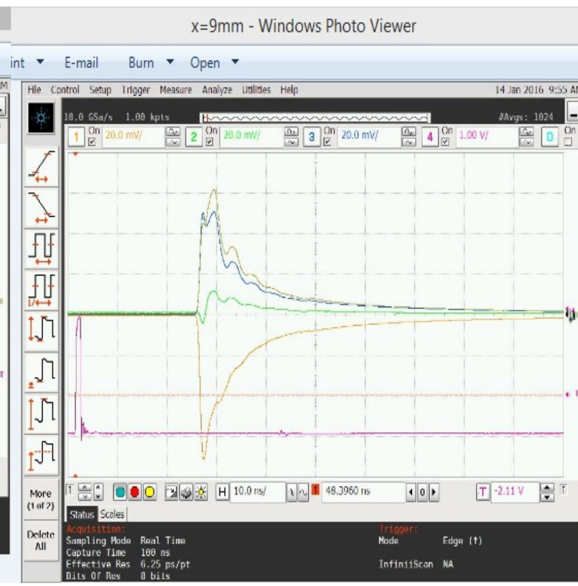
Scan mesh APD with 980nm LD

Scan the mesh APD active area with same 980nm laser light, x is the horizontal direction, y is the vertical direction.

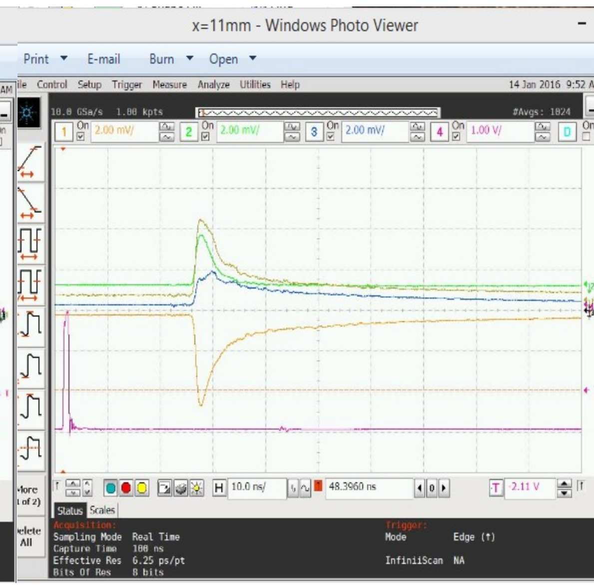
x = 7 mm, 200 mV/div.



x = 9 mm, 20 mV/div.



x= 1 1mm, 2 mV/div.

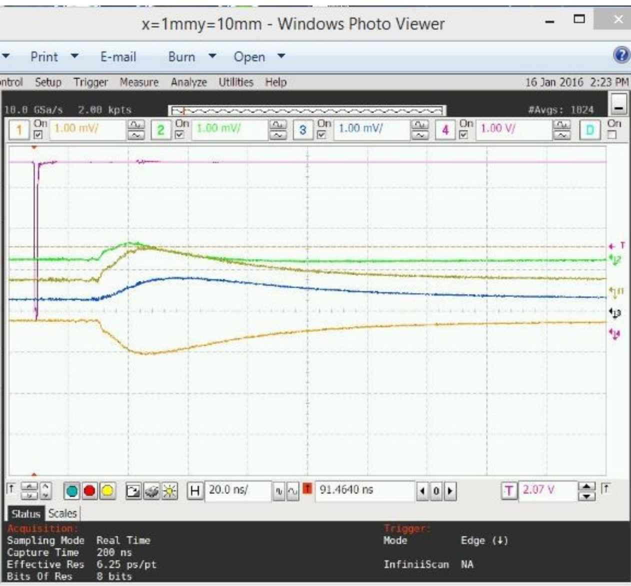


Cathode signal is always with smooth slower falling edge from -1 mm to 11 mm, but the mesh and anode signals at x = 7 mm and above show ripples on their falling edges.

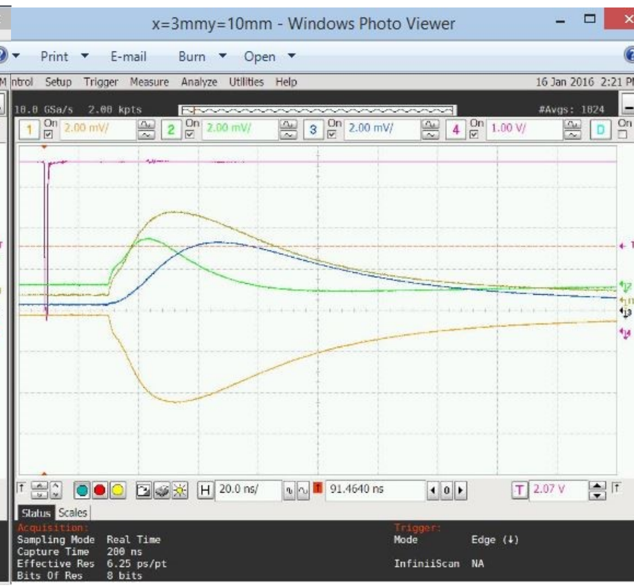
Scan mesh APD with 670nm Vcsel LD

Scan the mesh APD active area with 670nm laser light, x is the horizontal direction, y is the vertical direction.

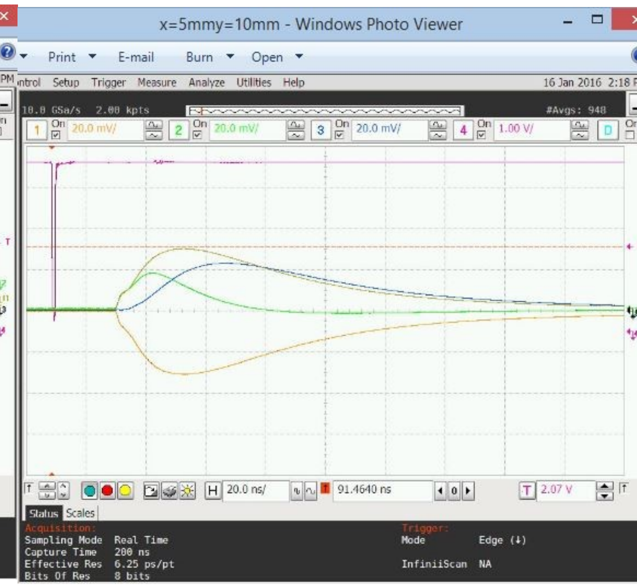
x = 1 mm, 1 mV/div.



x = 3mm, 2 mV/div.



x = 5 mm, 20 mV/div.

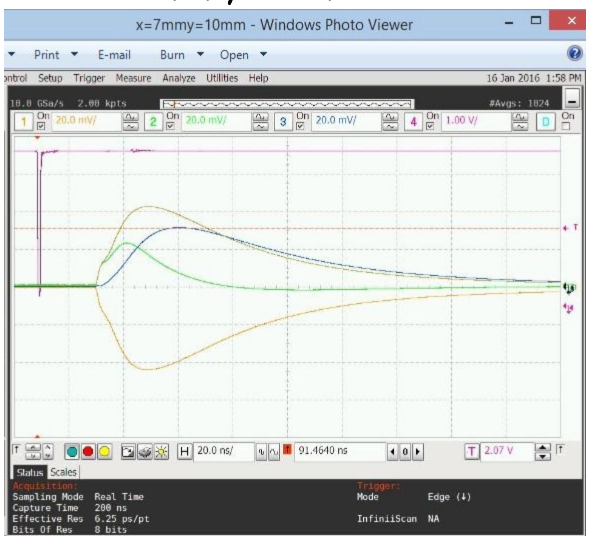


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1 mm to 15 mm, no ripples on their falling edges.

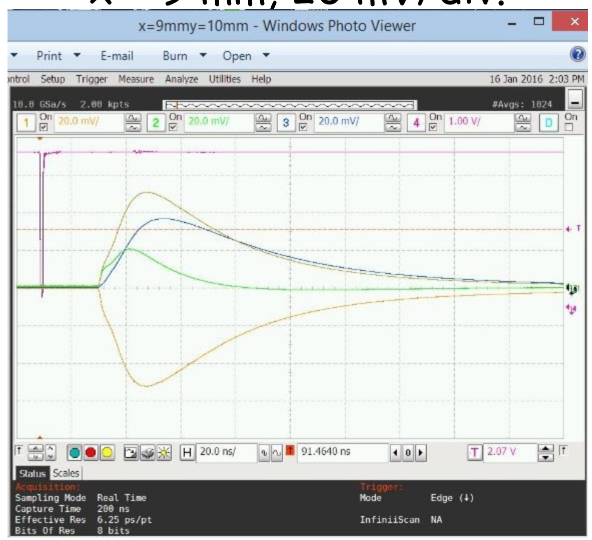
Scan mesh APD with 670nm Vcsel LD

Scan the mesh APD active area with 670nm laser light, x is the horizontal direction, y is the vertical direction.

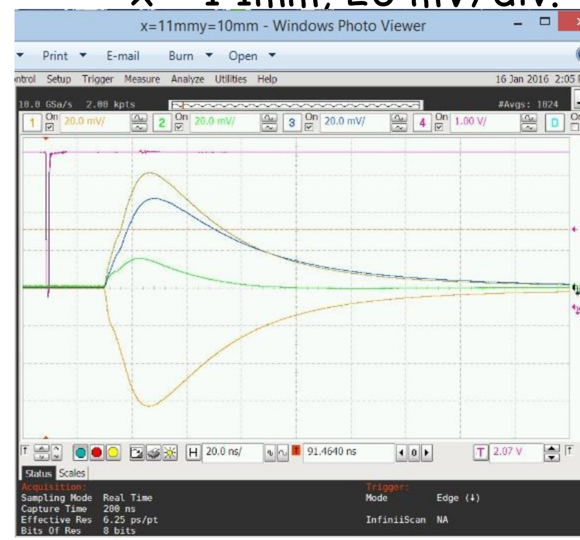
x = 7 mm, 20 mV/div.



x = 9 mm, 20 mV/div.



x = 1 1mm, 20 mV/div.

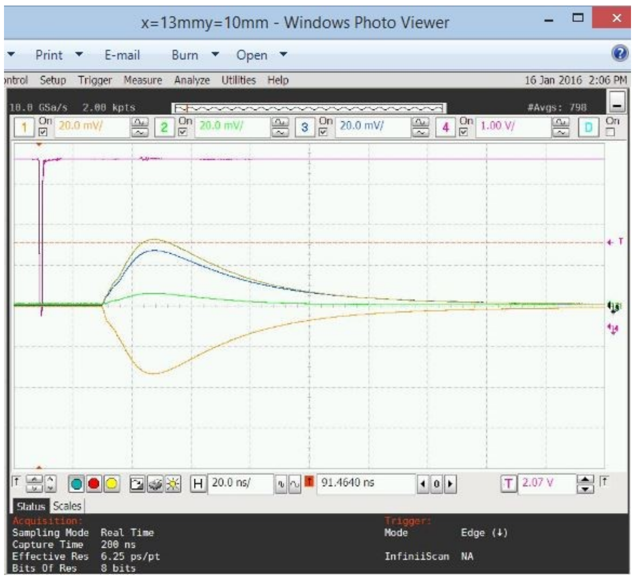


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1mm to 15 mm, no ripples on their falling edges.

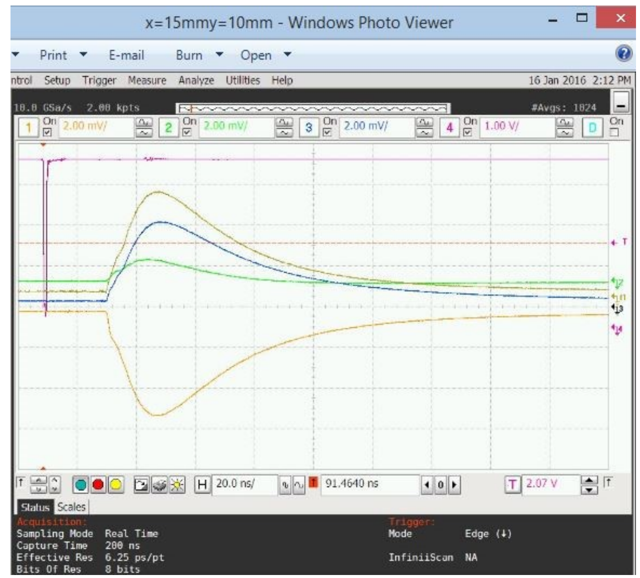
Scan mesh APD with 670nm Vcsel LD

Scan the mesh APD active area with 670nm laser light, x is the horizontal direction, y is the vertical direction.

x = 13 mm, 20 mV/div.



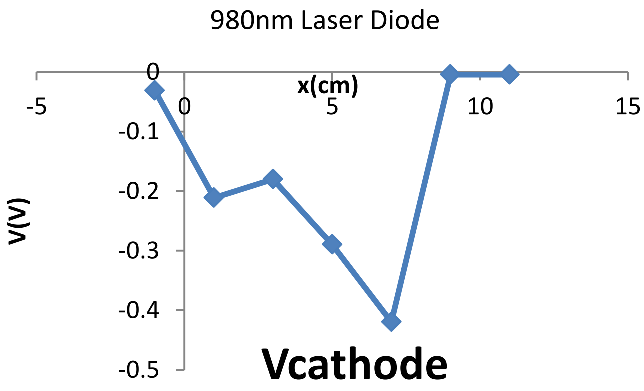
x = 15 mm, 2 mV/div.

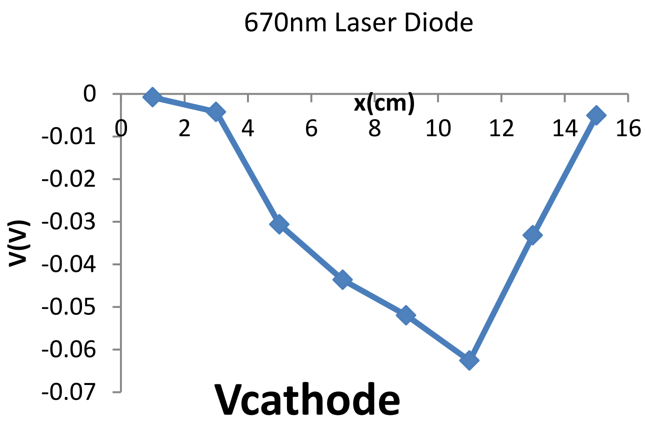


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1mm to 15 mm, no ripples on their falling edges.

Cathode signal amplitude distribution along x axis

Plot the cathode signal amplitude distribution along x axis for 980nm and 670nm laser diode.





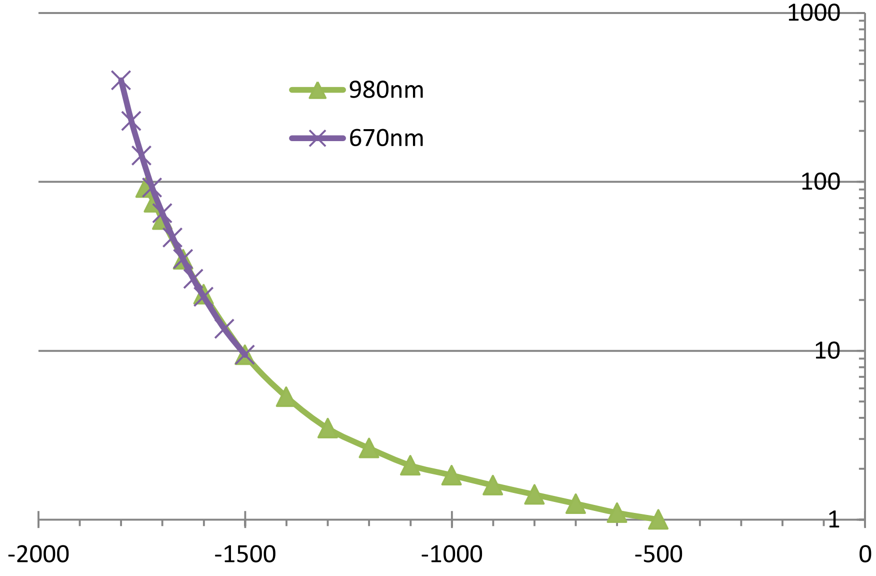
Absorption length of 670nm and 980nm in silicon

The absorption length μ of silicon ($T = e^{-L/\mu}$):
@670nm is 4.2μm, @980nm is 104μm, L is the thickness of silicon layer.

For 670nm laser light the photoelectrons are only created at the very first thin layer on the silicon surface, but for 980nm laser light it can penetrate deep into the entire APD active layer. The reason to cause signal shape difference might be due to this, it needs detailed simulation to confirm.

APD Gain vs. HV

We measured relative APD gain:



The experimental gain curve calibration has uncertainty: choose which point as gain unity? Talked to Mickel of RMD, he prefered to choose HV @ -500V as gain unity, so do we that here.

Fe55 source spetrum

Set APD HV at -1800V, take Fe55 source trigger events, then plot the cathode signal amplitude spectrum: