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

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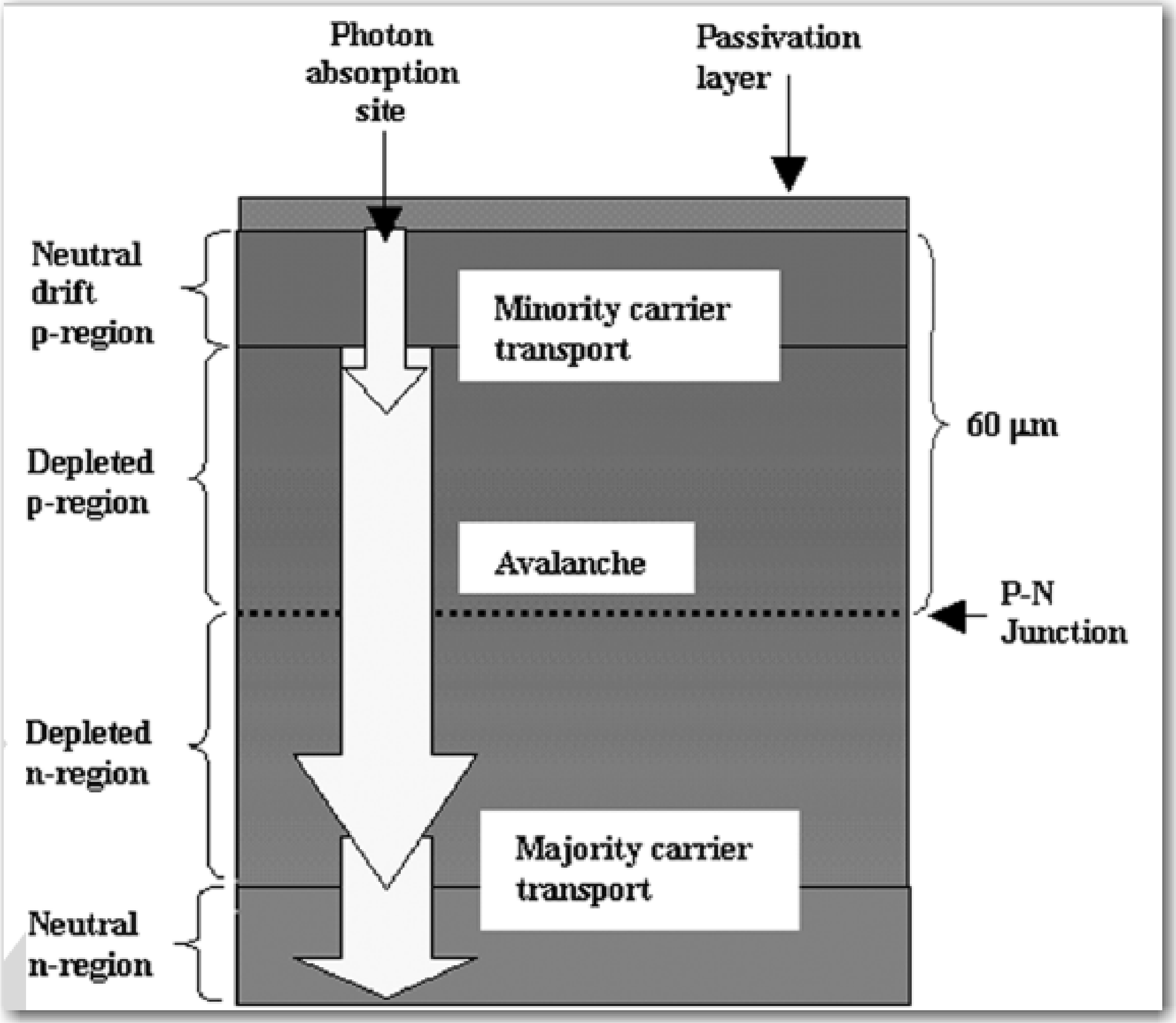
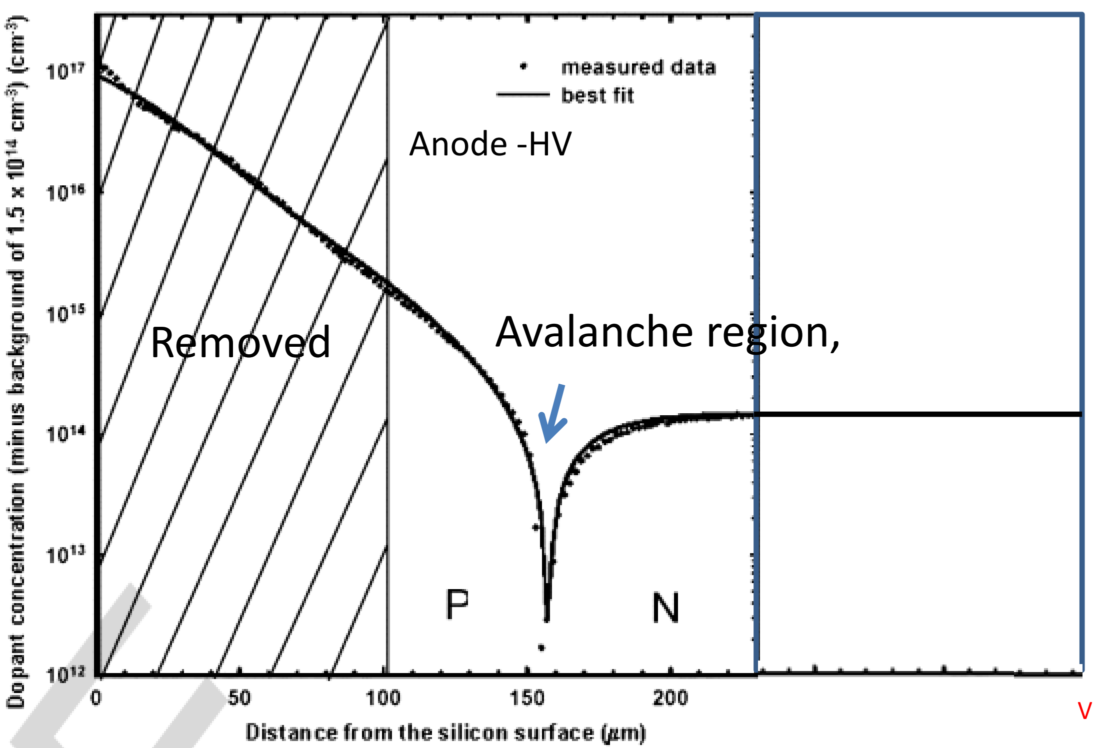
RMD deep diffused APD structure



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



Cathode +HV

V

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.

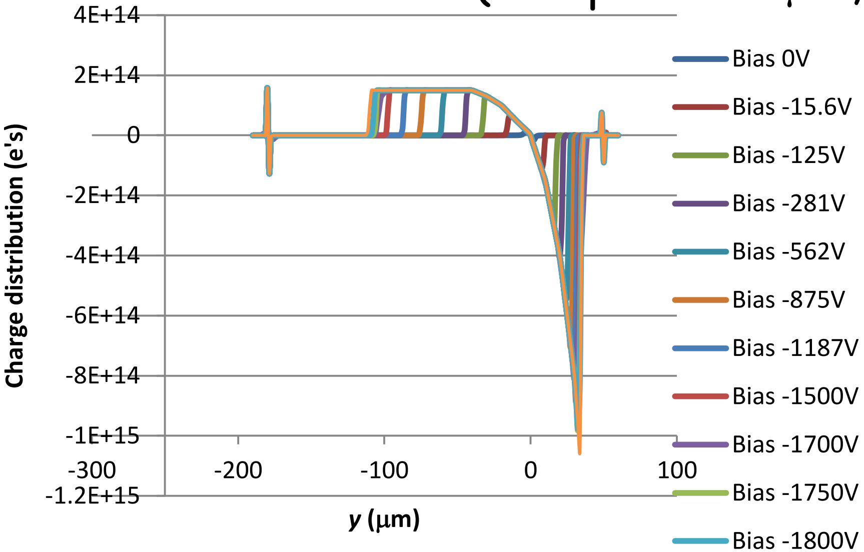
P doping: Al
N doping: Ga

E

Calculation of E-field in the APD

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

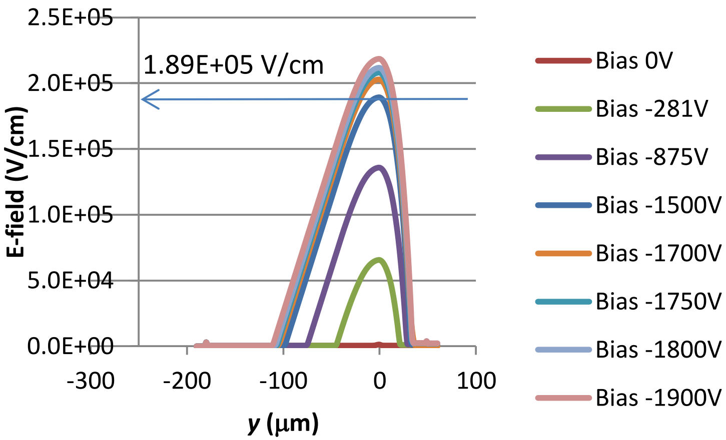
Extract the net charge distribution along with the central line of the APD model (x kept at 50 μm, y from -190 μm to 60 μm):



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:

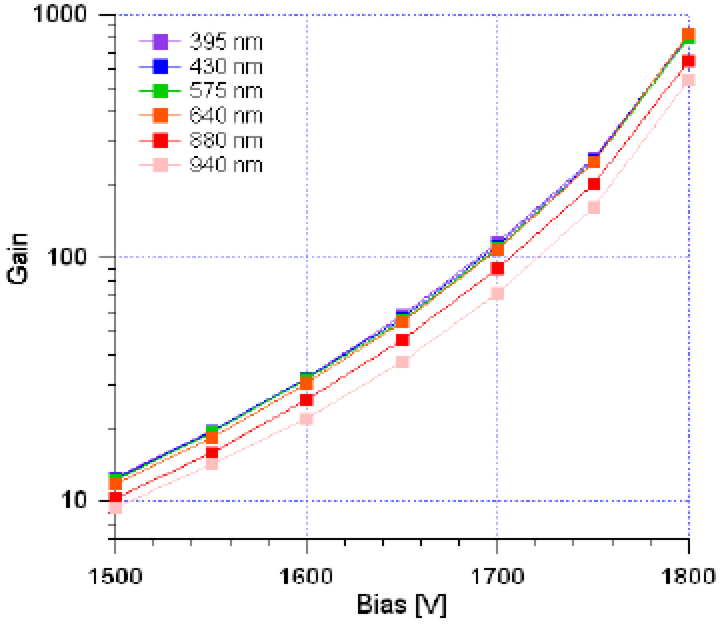
$E_y(V/cm) = 1/\varepsilon \int q\,dy$, $\varepsilon = 11.7 \times 8.85 \times 10^{-14}$ (F/cm), *q is the charge density (as shown on the left), integration from -190 μm to 60 μm.*



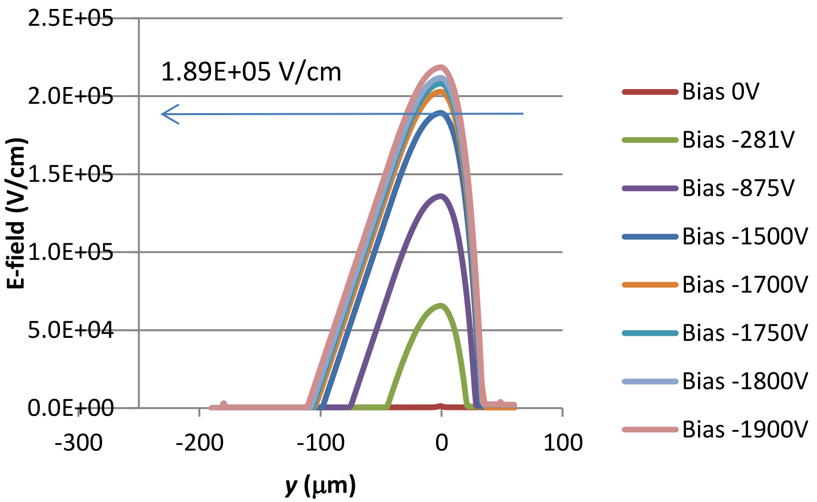
The maximum E-field for -1500V bias is ~189 kV/cm.

Avalanche region in APD

To estimate the thickness of the avalanche region in APD, we assume the avalanche starts at bias -1500 V. On previous slide we have shown that at -1500 V the maximum *E*-field is ~ 189 kV/cm, thus we can draw a line on the right plot, estimate the thickness of the avalanche region t.



(M. McClish et al. IEEETNS 53 (2006) 1)



At -1700 V, t ~ 30 μm,
-1750 V, t ~ 33.8 μm,
-1800 V, t ~ 36.3 μm,
-1900 V, t ~ 42.5 μm.

Test mesh APD with red laser diode (670nm)

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

Test mesh APD with red laser diode (670nm)

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

Test mesh APD with red laser diode (670nm)

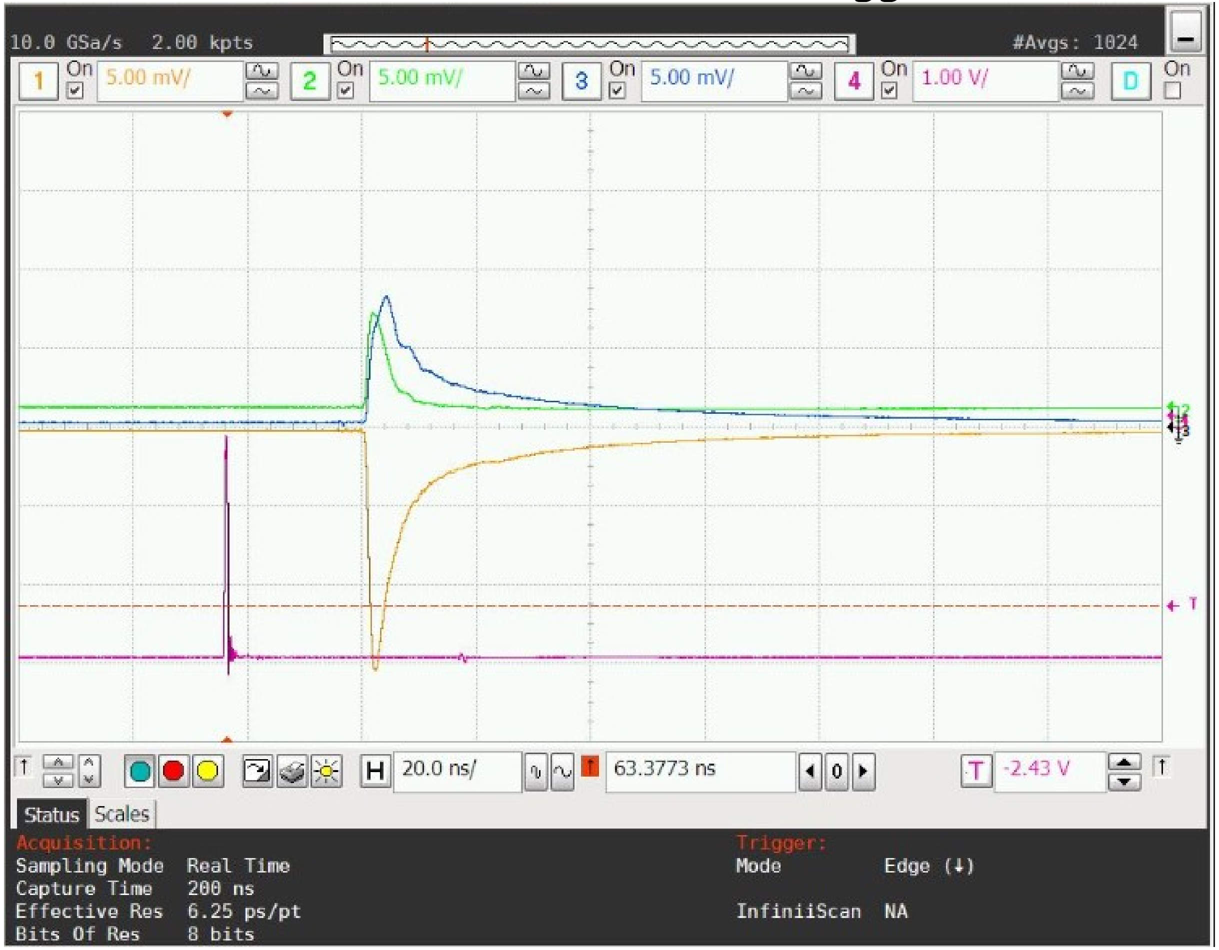
HP pulser settings: Width=3ns, Vhigh=4V, Vlow=0V, Comp=Off
Ch1=Cathode; Ch2=Mesh; Ch3=Anode; Ch4=Trigger

Test mesh APD with red laser diode (670nm)

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

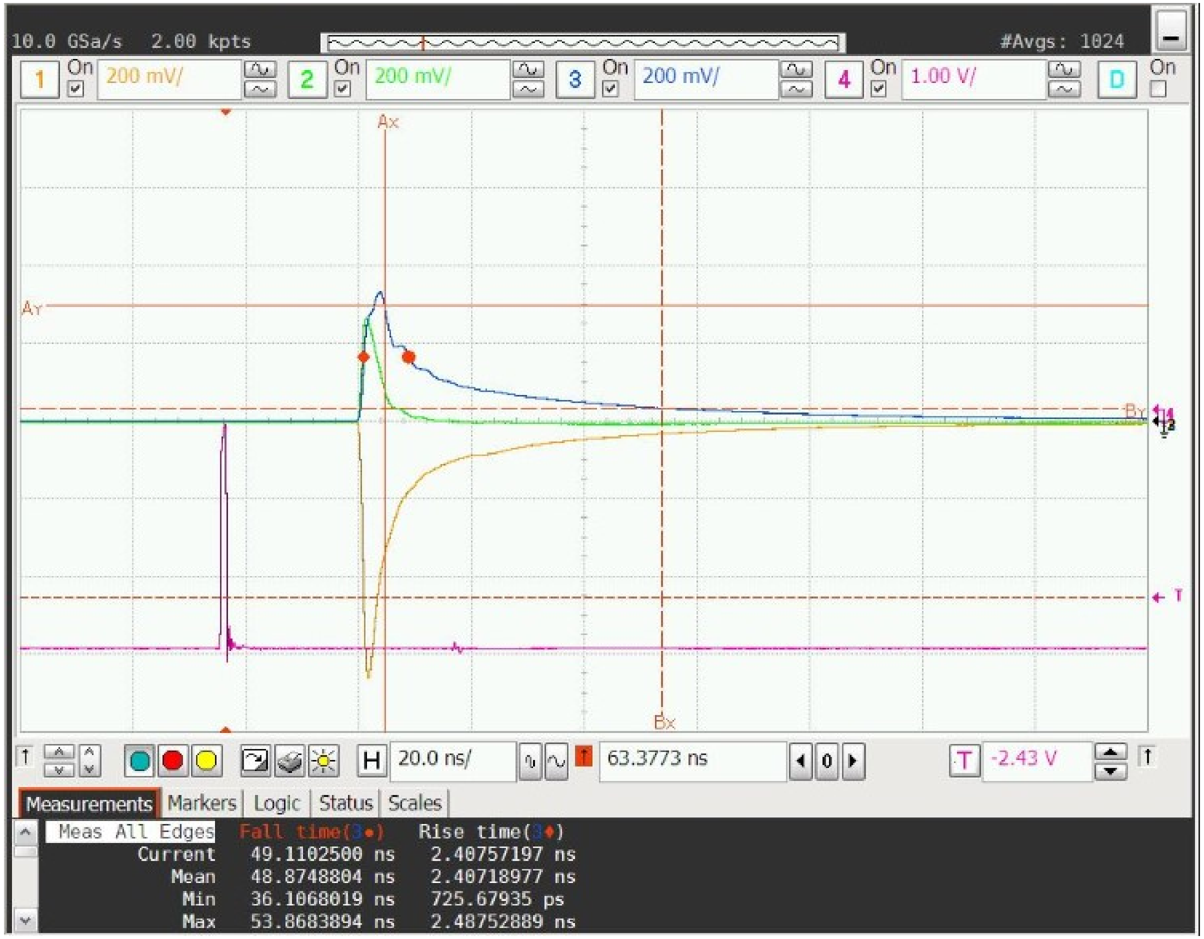
Test mesh APD with infrared laser diode (980nm)

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



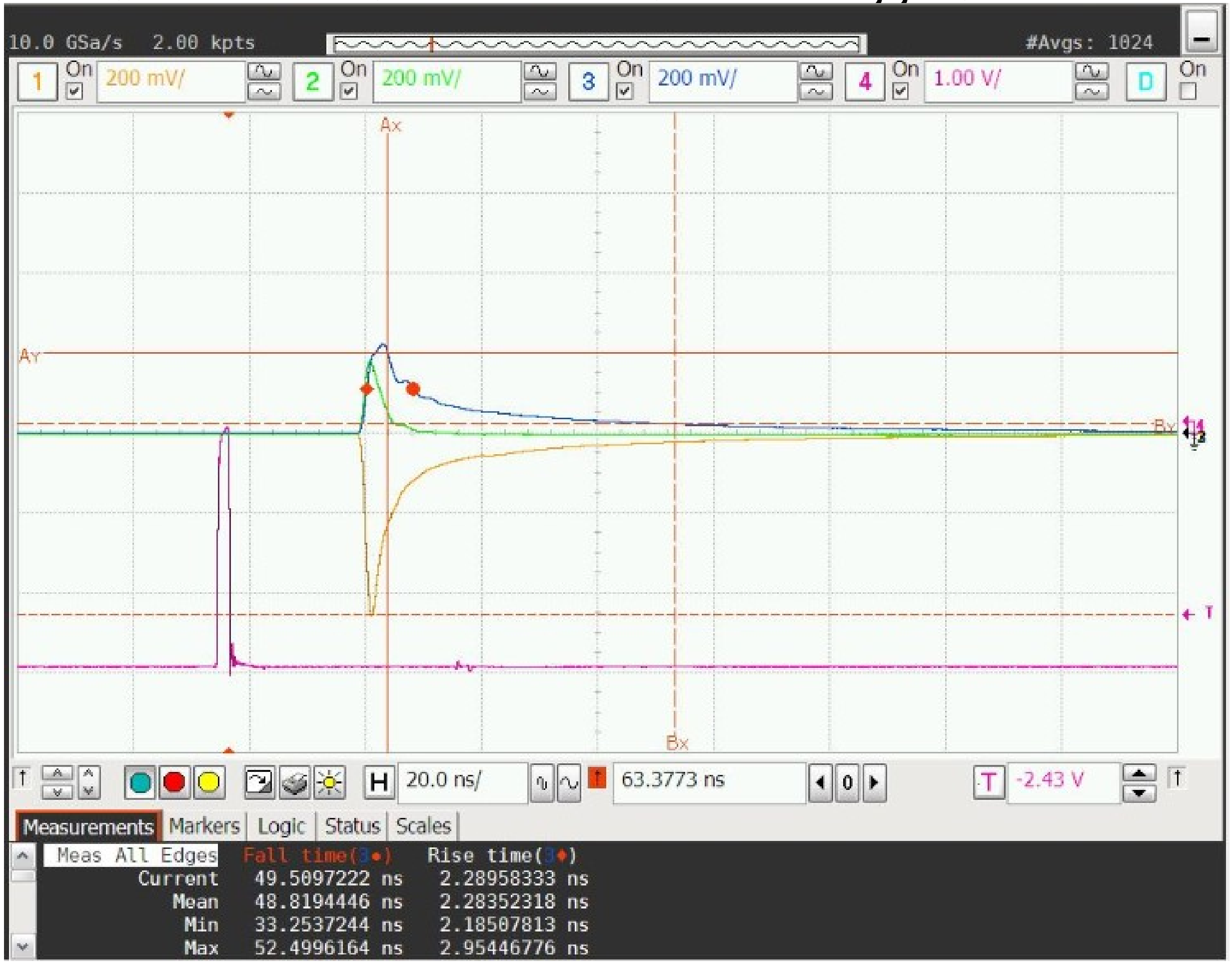
Test mesh APD with infrared laser diode (980nm)

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



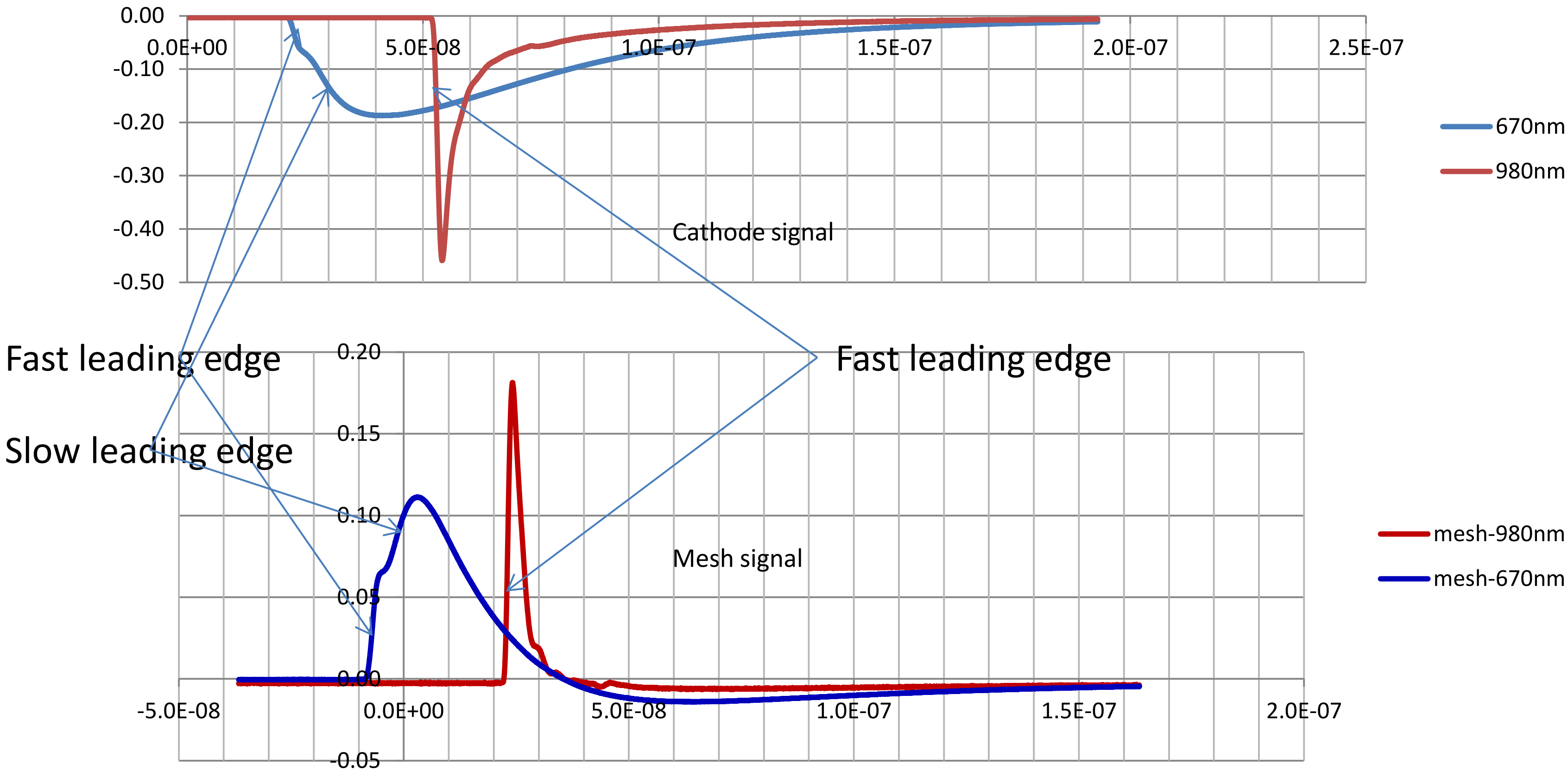
Test mesh APD with infrared laser diode (980nm)

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



Comparison between 670nm and 980nm

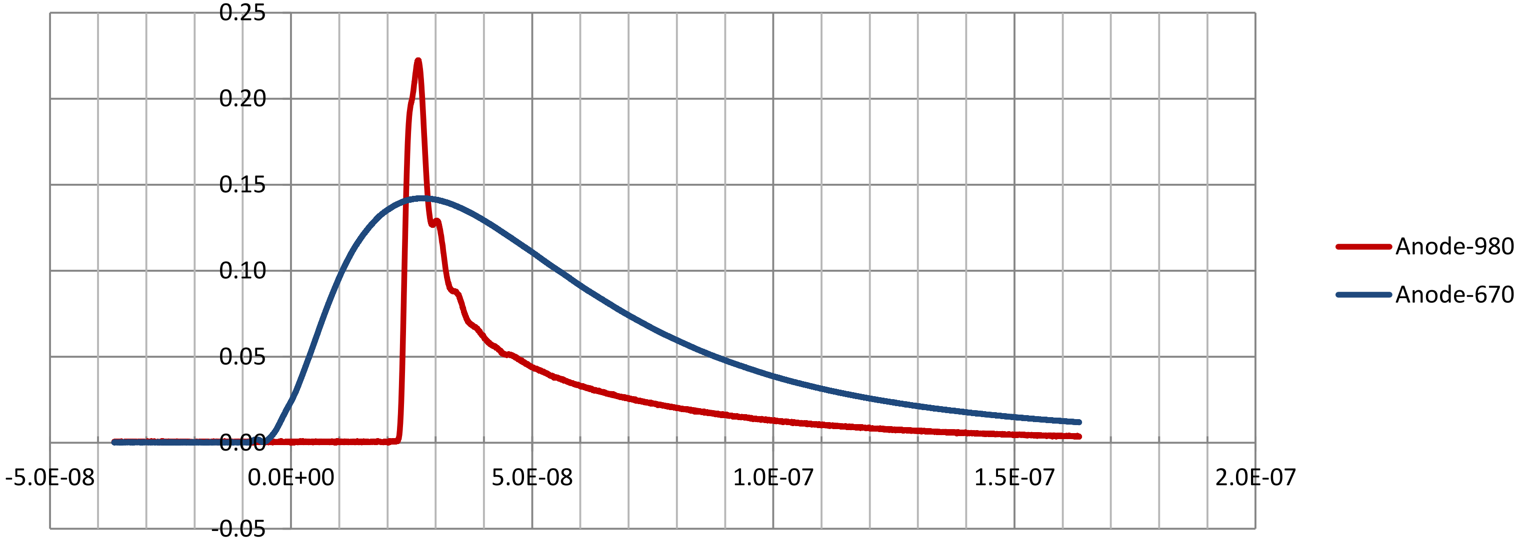
HP pulser settings: Width=2ns



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=2ns

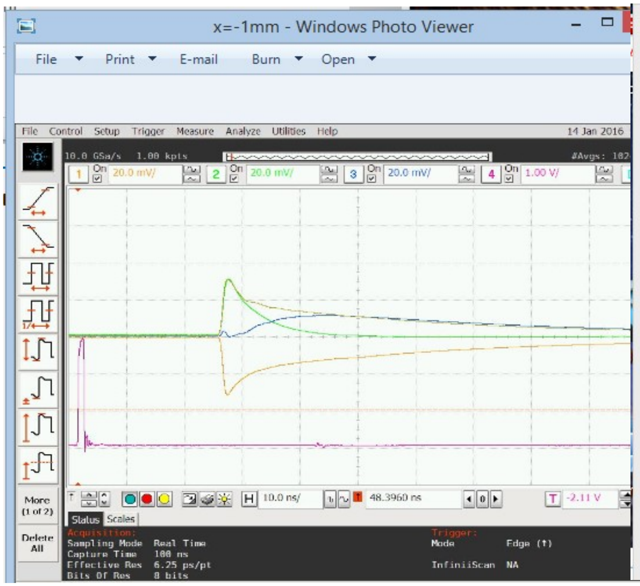


For anode signal we don't see the fast leading edge, only slow rising edge!

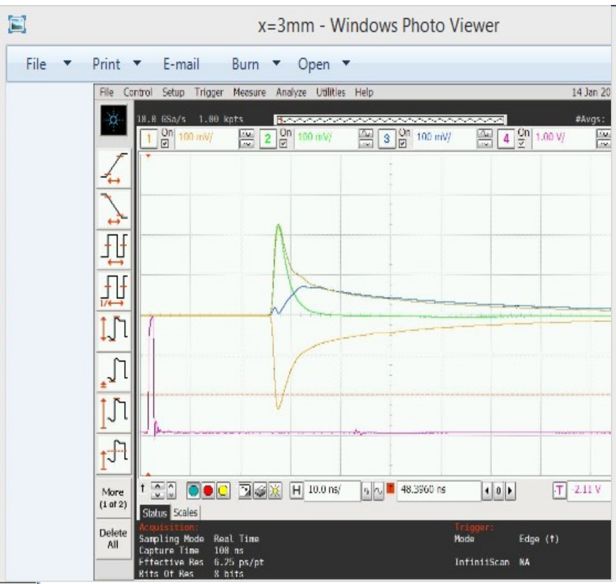
Scan mesh APD with 980nm LD

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.

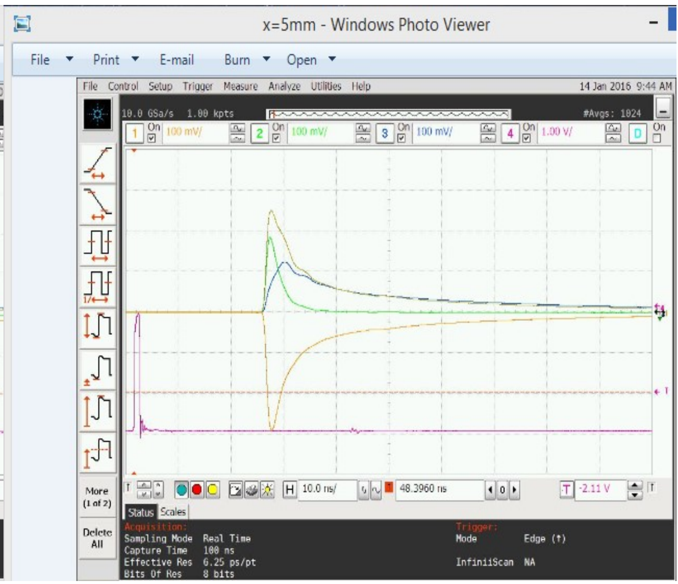
X=-1mm, 20mV/div.



X=3mm, 100mV/div.



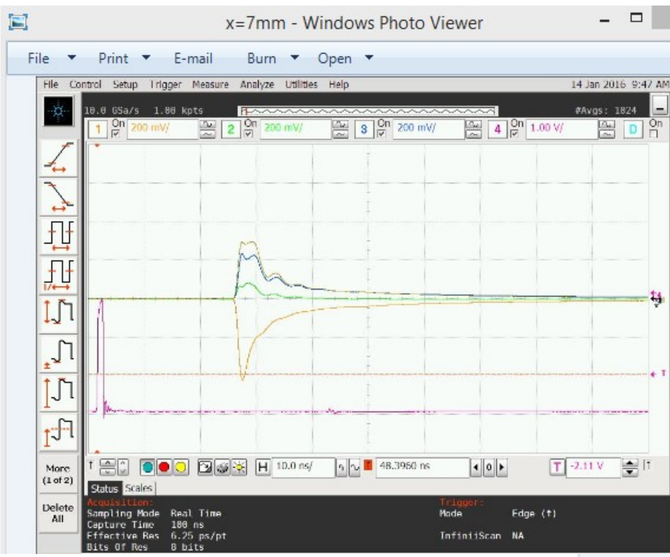
X=5mm, 100mV/div.



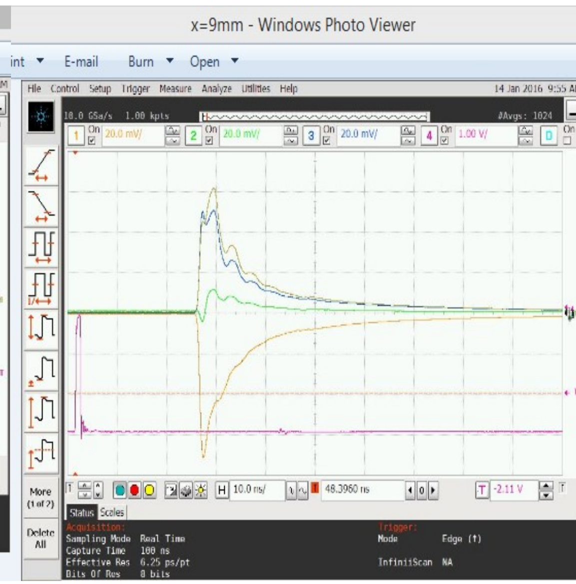
Scan mesh APD with 980nm LD

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

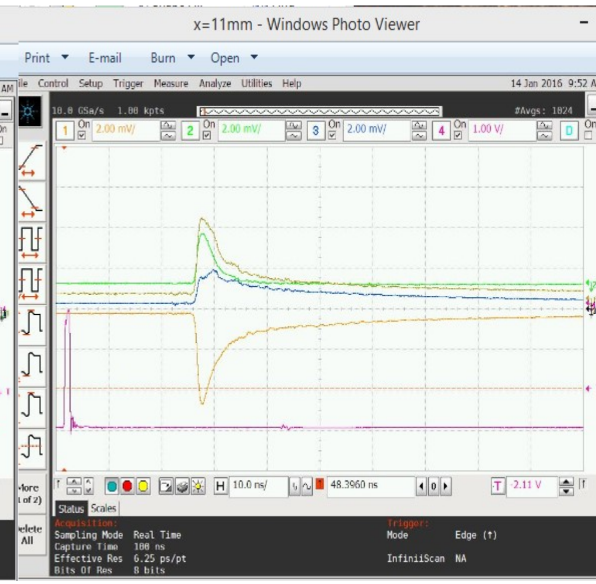
X=7mm, 200mV/div.



X=9mm, 20mV/div.



X=11mm, 2mV/div.

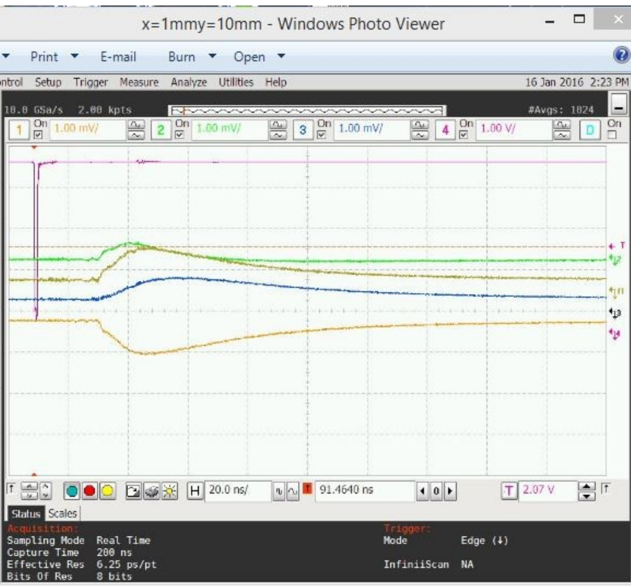


Cathode signal is always with smooth slower falling edge from -1mm to 11mm, but the mesh and anode signals at x=7mm and above show ripples on their falling edges.

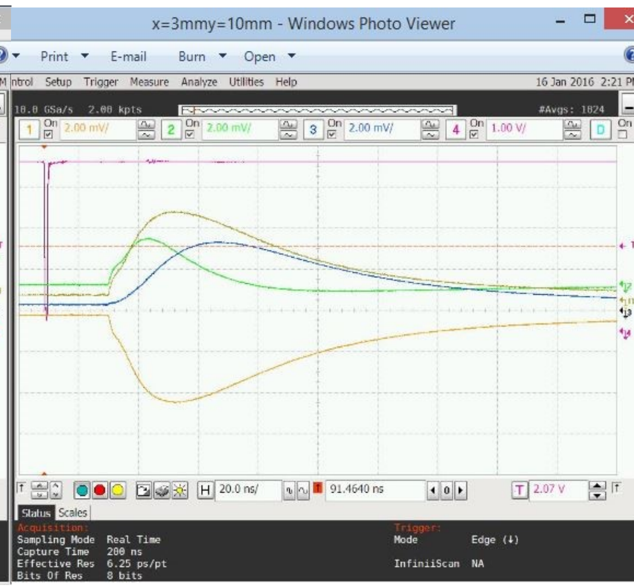
Scan mesh APD with 670nm Vcsel LD

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

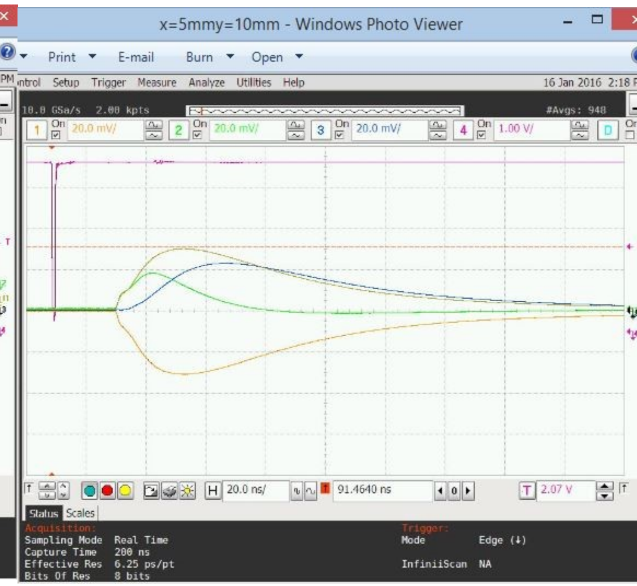
X=1mm, 1mV/div.



X=3mm, 2mV/div.



X=5mm, 20mV/div.

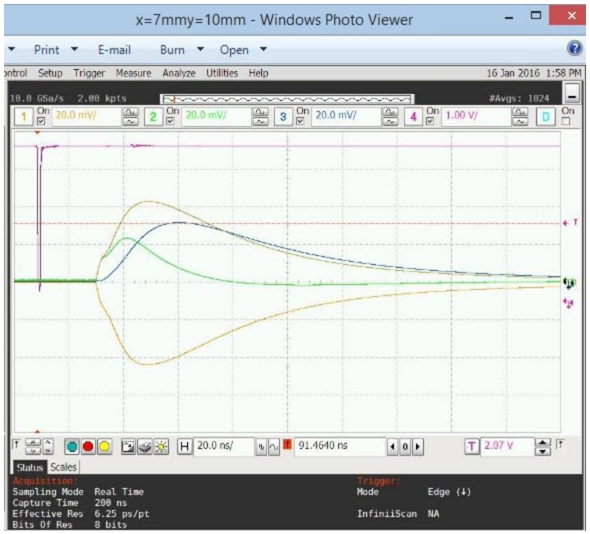


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1mm to 15mm, no ripples on their falling edges.

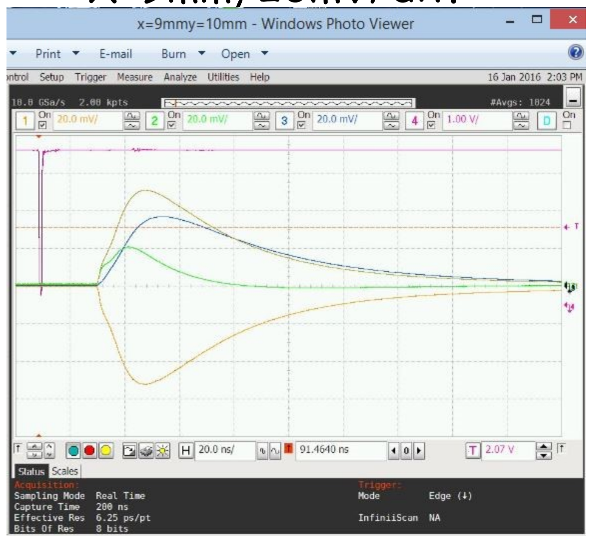
Scan mesh APD with 670nm Vcsel LD

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

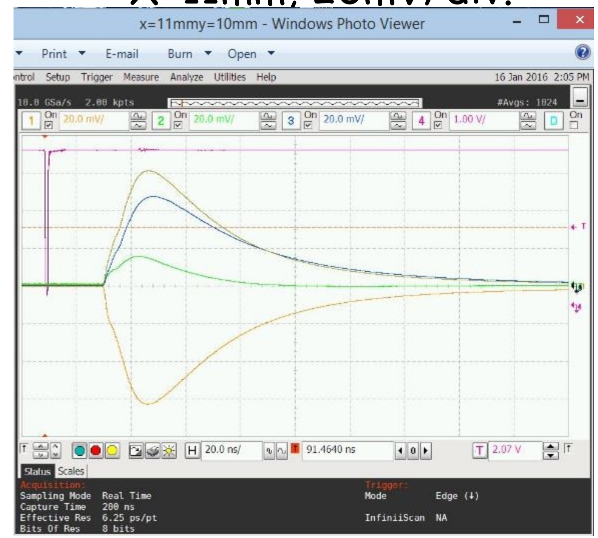
X=7mm, 20mV/div.



X=9mm, 20mV/div.



X=11mm, 20mV/div.

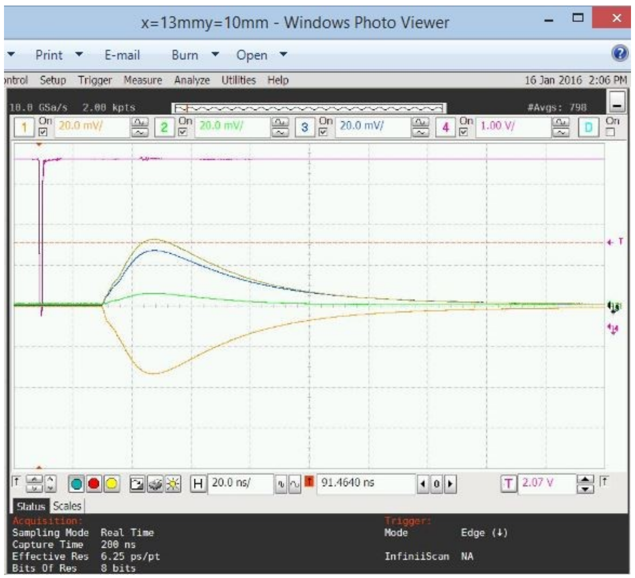


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1mm to 15mm, no ripples on their falling edges.

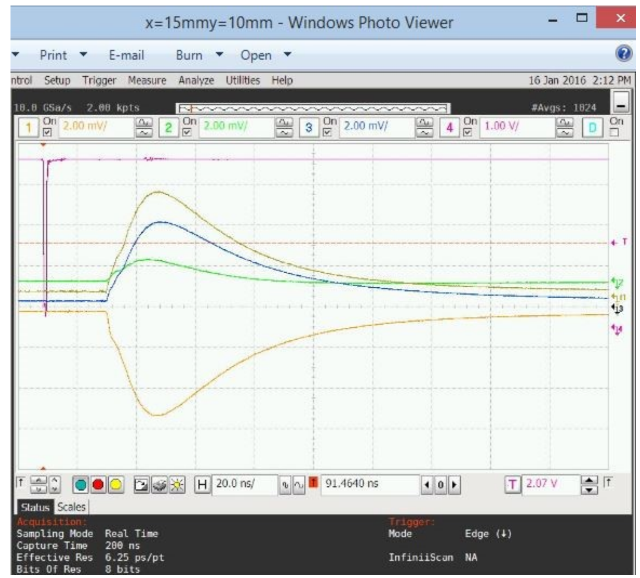
Scan mesh APD with 670nm Vcsel LD

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

X=13mm, 20mV/div.



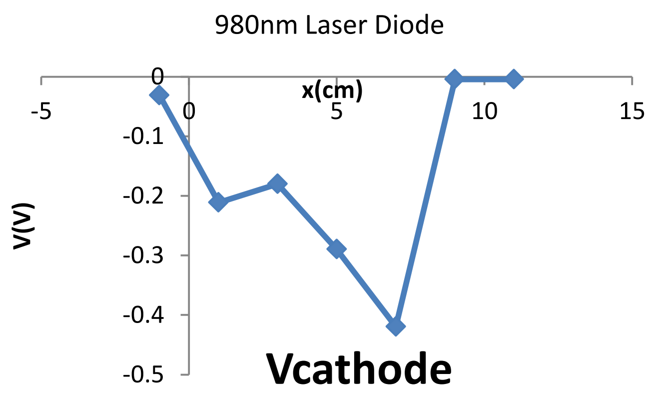
X=15mm, 2mV/div.

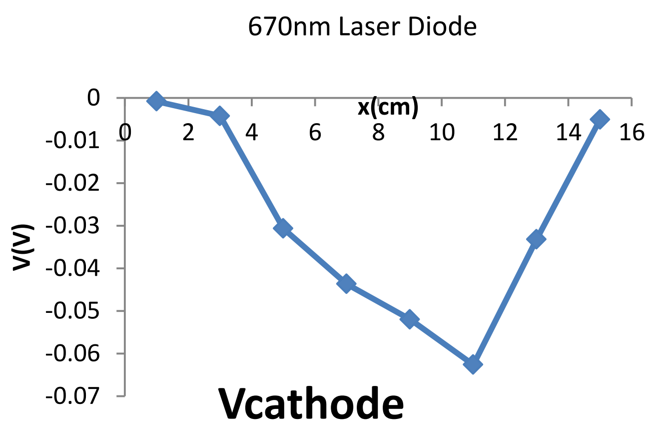


Different from 980nm laser case, all cathode, mesh and anode signals are with smooth falling edge from 1mm to 15mm, no ripples on their falling edges.

Cathode signal amplitude distribution along x axis

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





Comparison between 670nm and 980nm

The absorption length μ of silicon ($T = e^{-\mu L}$)
@670nm is 1/4.2μm, @980nm is 1/104μm, L is the thickness of silicon layer.
For 670nm laser light the photoelectrons are only created at the very thin layer of 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.