# 3D Sensor Characterization, Electrode Capacitance Measurements

Martin Hoeferkamp, Sally Seidel, Igor Gorelov
University of New Mexico

8th RD50 Workshop, Prague
27 June 2006

# Introduction

- Motivation: a need for 3D sensors to have an electrode capacitance compatible in value with existing front end chip requirements.
- Eg. , ATLAS Pixel detector upgrade, 3D sensors on TOTEM experiment will use ATLAS front end chip.
- Measured values on the order of 100fF, difficult with LCR meter
- An alternative method of capacitance measurement is presented.

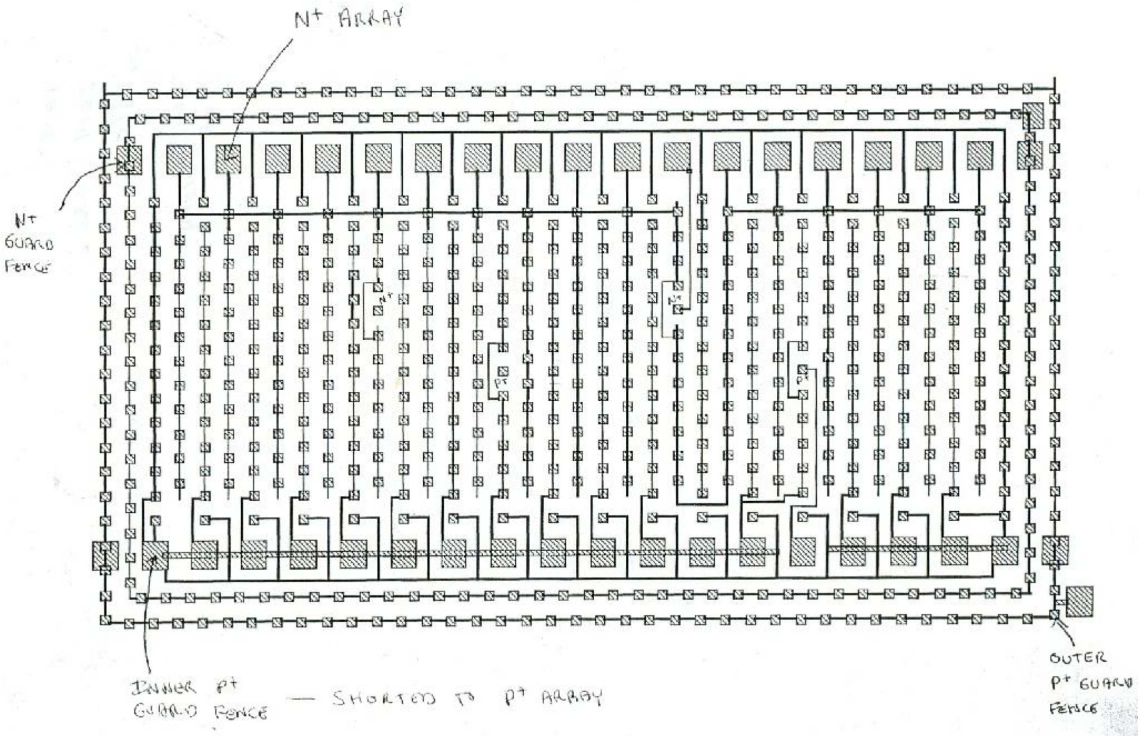
- 3D sensors received from Sherwood Parker (Hawaii U.) and Chris Kenney (Stanford U.) include:

  - non-irradiated sensor

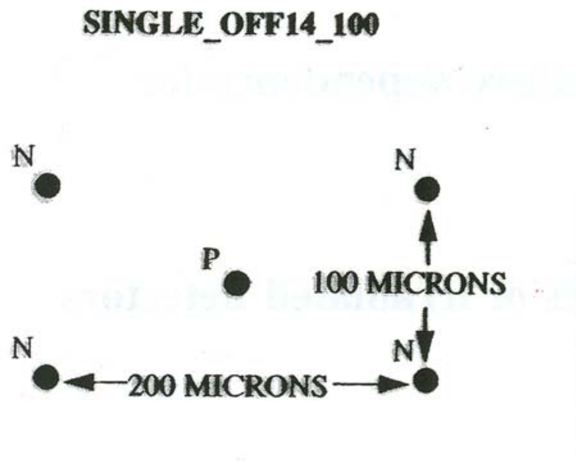
  - irradiated 3D sensors
    - $2x10^{14}$ $cm^{-2}$ 55 MeV proton
    - $1x10^{15}$ $cm^{-2}$ 55 MeV proton

# 3D Sensor Configuration

- Configuration of Measured Devices
  - Alternating columns of n- and p-electrodes
  - Most electrodes are connected together along each column
  - Some electrodes are left isolated, to be contacted and measured individually




- Top view layout

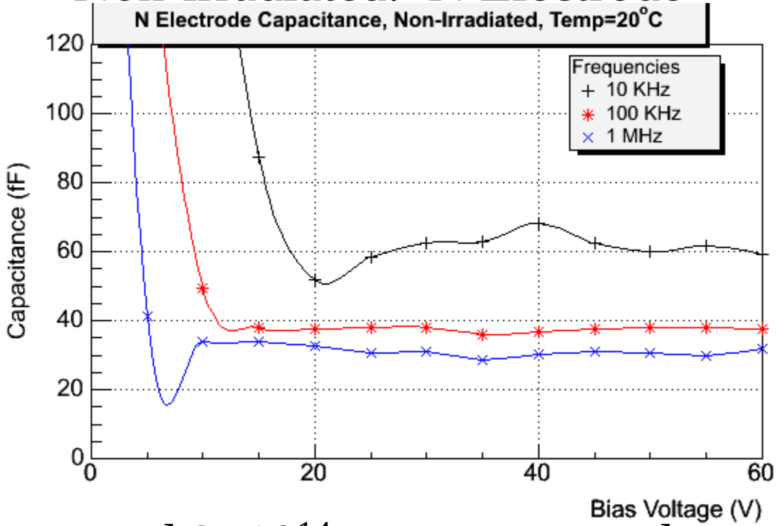



- Layout dimensions
( not same as ATLAS pixel)

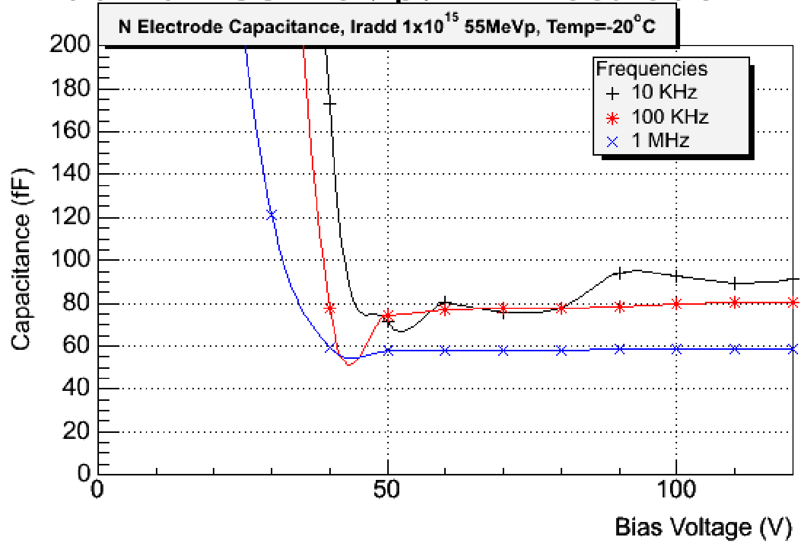
# Electrode Capacitance, direct meas.

- Direct Measurement uses standard CV measurement with LCR meter (HP4284A)

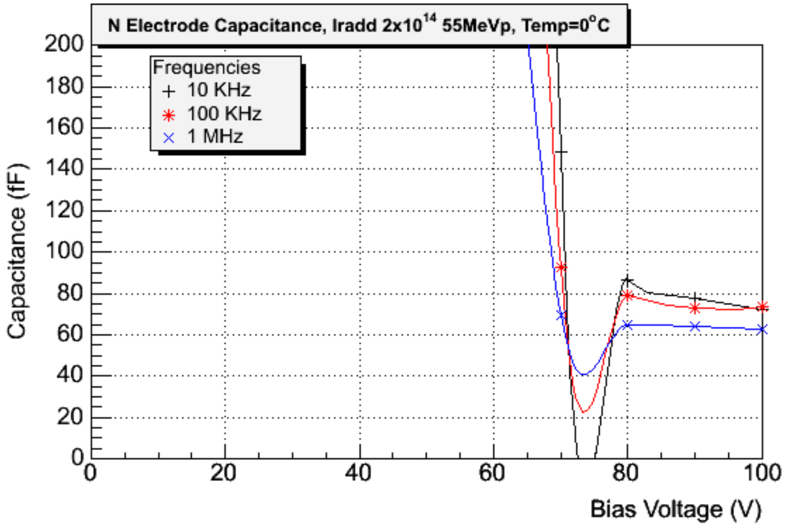
- Non-irradiated: N Electrode




- Irrad $10^{15}$ 55MeVp: N Electrode




- Irrad $2\times10^{14}$ 55MeVp: N Electrode




**Result: very low electrode capacitance**

**Cnon-irrad N ~ 59fF(10KHz), 38fF(100KHz), 32fF(1MHz)**

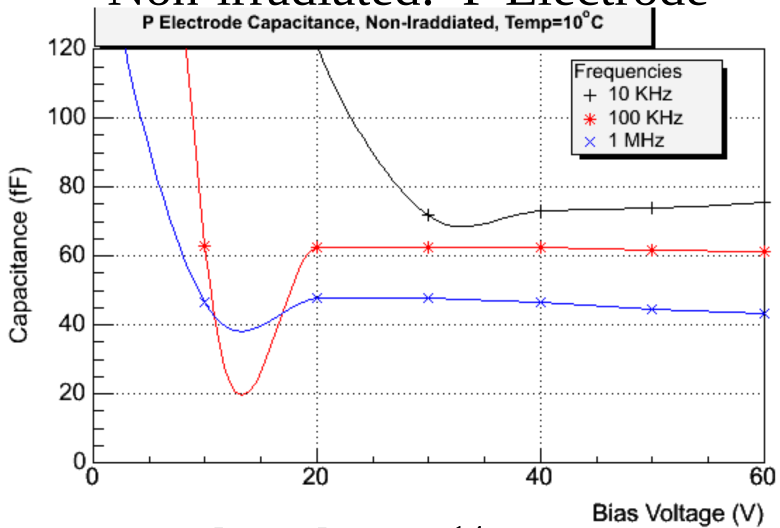
**Cirrad $2\times10^{14}$ N ~ 72fF(10KHz), 72fF(100KHz), 62fF(1MHz)**

**Cirrad $1\times10^{15}$ N ~ 91fF(10KHz), 80fF(100KHz), 60fF(1MHz)**

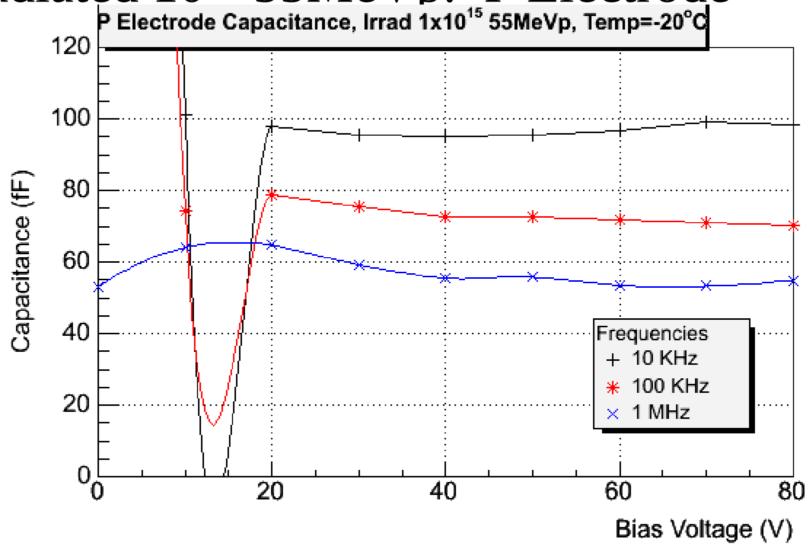
Martin Hoeferkamp,UNM

# Electrode Capacitance, direct meas.

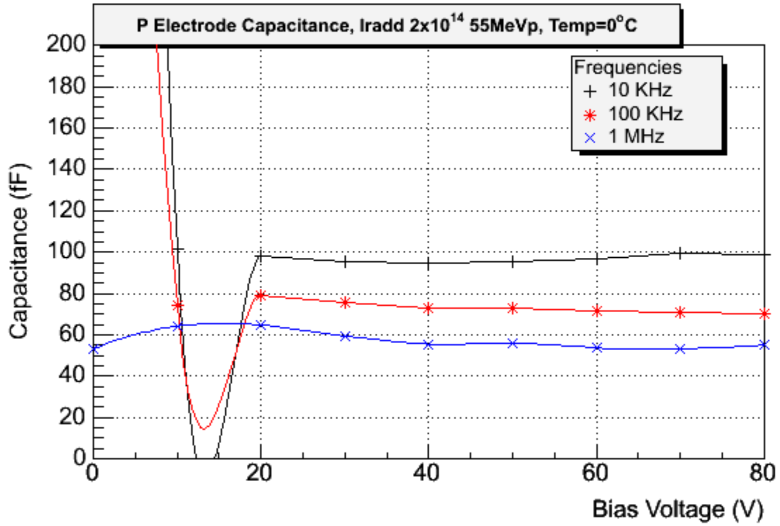
- Direct Measurement using LCR meter (HP4284A)
- Non-irradiated: P Electrode




- Irradiated $10^{15}$ 55MeVp: P Electrode




- Irradiated $2\times10^{14}$ 55MeVp: P Electrode




**Result: very low electrode capacitance**

**Cnon-irrad P ~ 71fF(10KHz), 58fF(100KHz), 46fF(1MHz)**

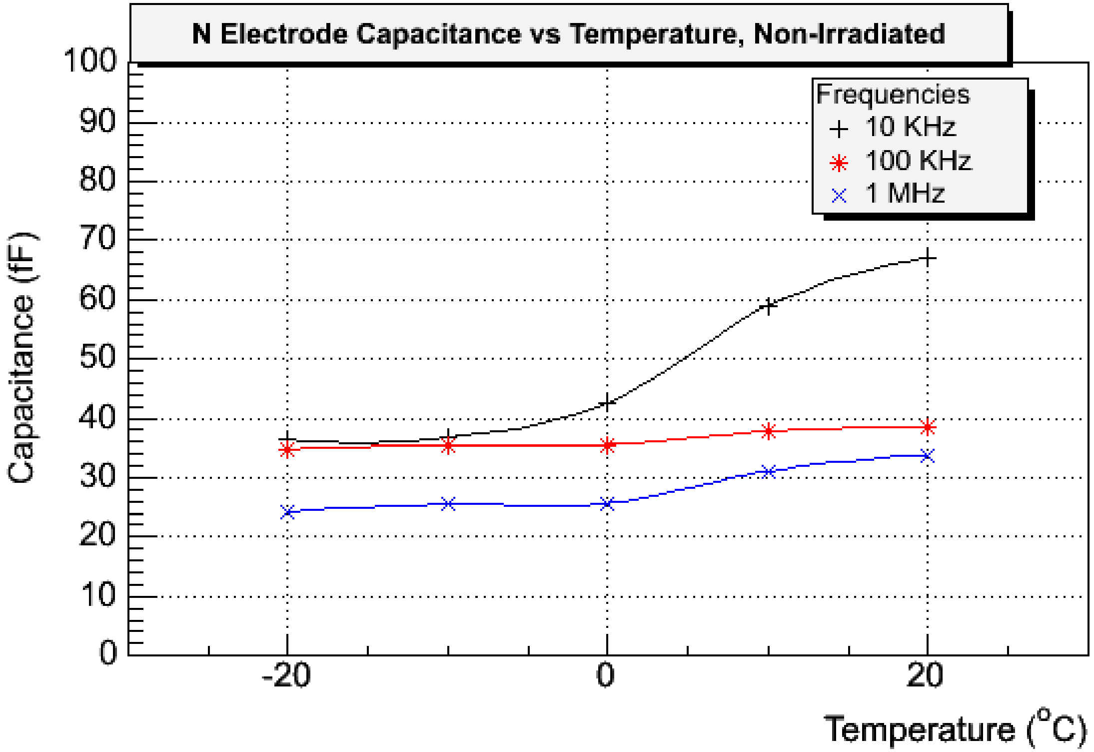
**Cirrad $2\times10^{14}$ P ~ 96fF(10KHz), 69fF(100KHz), 53fF(1MHz)**

**Cirrad $1\times10^{15}$ P ~ 98fF(10KHz), 70fF(100KHz), 55fF(1MHz)**

Martin Hoeferkamp,UNM

# Electrode Capacitance, direct meas.

- Direct Measurement using LCR meter (HP4284A)
- Non-irradiated: N Electrode



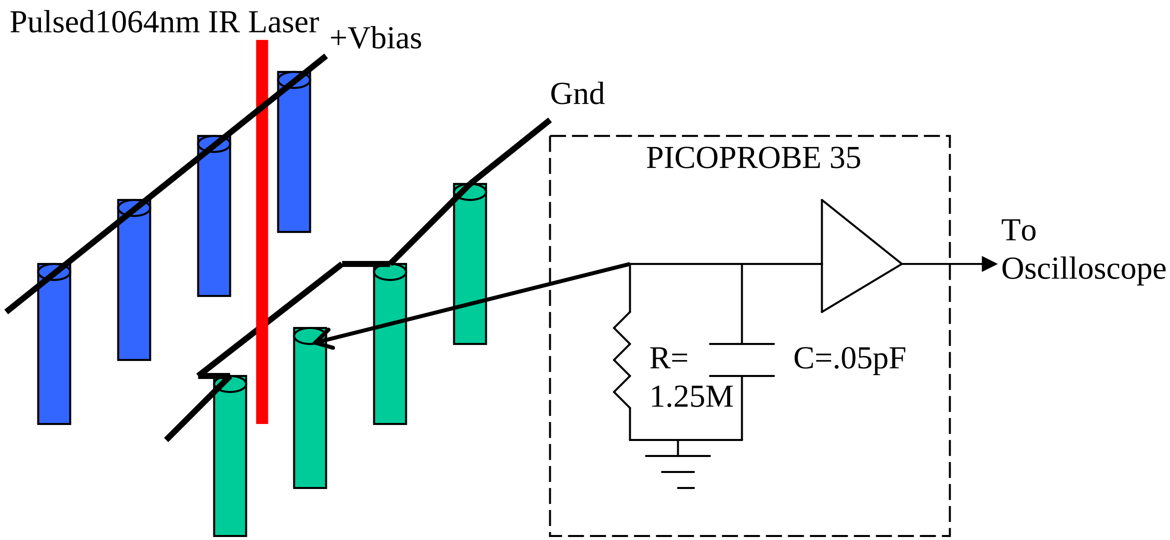

**Result: electrode capacitance decreases with lower temperature, and reaches a minimum value at ~ -10°C.**

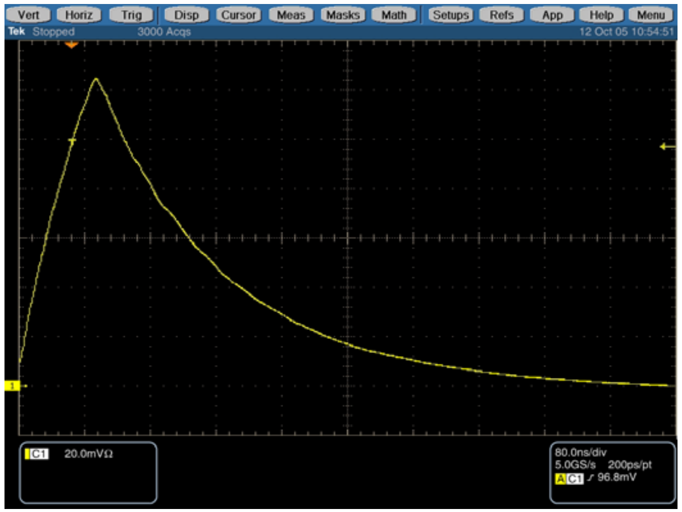
# Electrode Capacitance, direct meas.

- Dependence of CV characteristics on measurement frequency
- The frequency dependence is observed at every temperature.
- Frequency dependence of irradiated sensors is due to the finite reaction time of the deep traps which respond better to lower frequency signals (Lancaster U.).
- The capacitances are higher for more heavily irradiated sensors
- There is a temperature dependence of the capacitance at a fixed measurement frequency.
- **Capacitance depends on the frequency and the temperature, same as for planar sensors.**

# Electrode Capacitance, indirect meas.

- Indirect Measurement using Decay Time of IR pulse on an isolated electrode.
- Electrode is grounded through input impedance of a Picoprobe 35.
- The IR laser induced charge is collected, rising signal on measured pulse.
- When the laser is turned off the signal decay follows an exponential with a time constant = $R*(C+C_{3D})$ , referred to here as RC time constant.
- $C_{3D}$ is extracted from the decay time constant using values of probe resistance and capacitance.

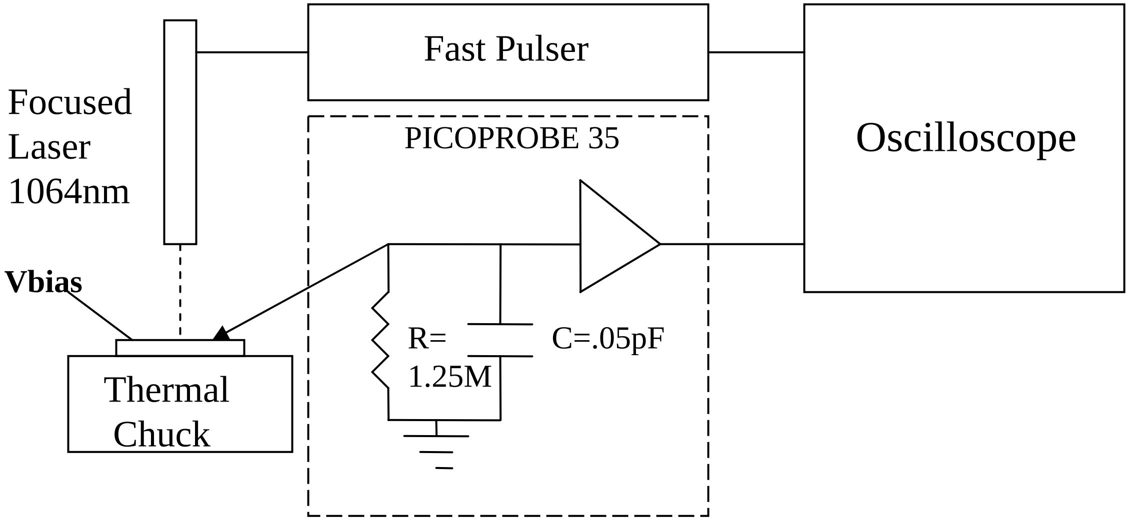





Martin Hoeferkamp,UNM

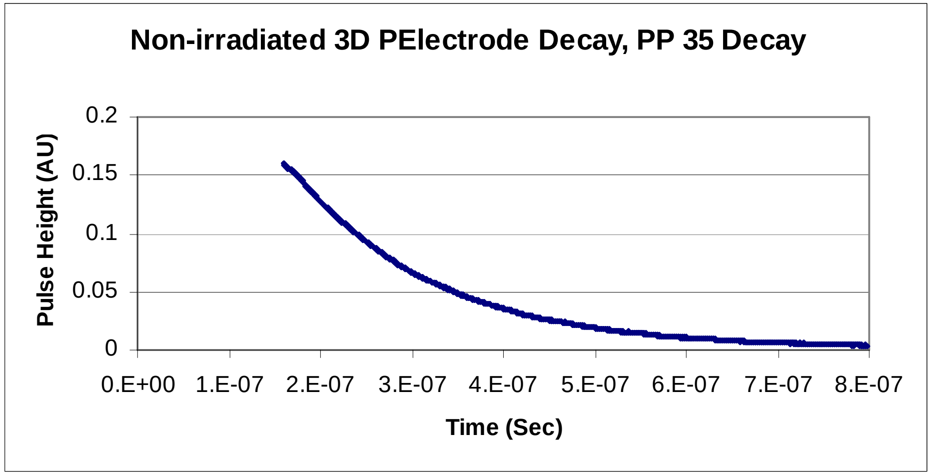
# Electrodde Capacitance, indirect meas.

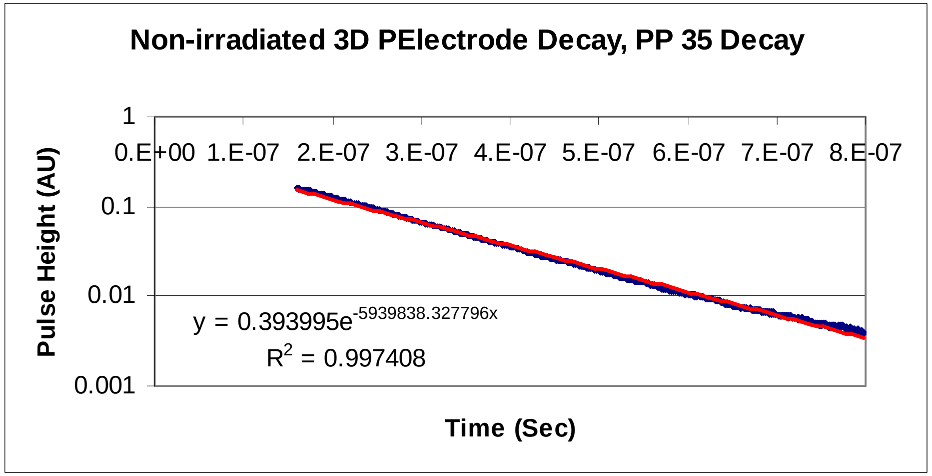



- Laser: 1064 nm EG&G
- Probes: Picoprobe 35 26GHz BW, Cascade Microtech coaxial
- Oscilloscope: Tektronix TDS7254 2.5Ghz BW
- Thermal Chuck: Micromanipulator (-60$^{o}$C )

# Electrode Capacitance, indirect meas.

- Indirect Measurement using Decay Time Picoprobe 35 signal, Non-irradiated p-electrode

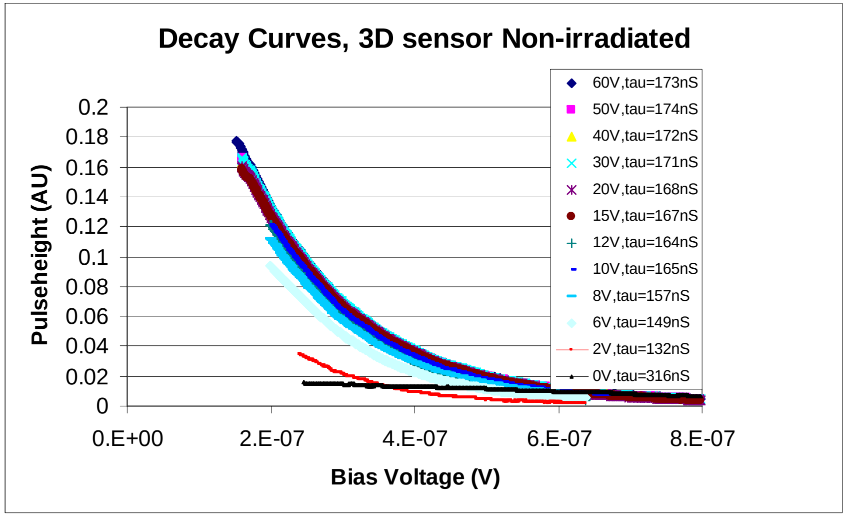


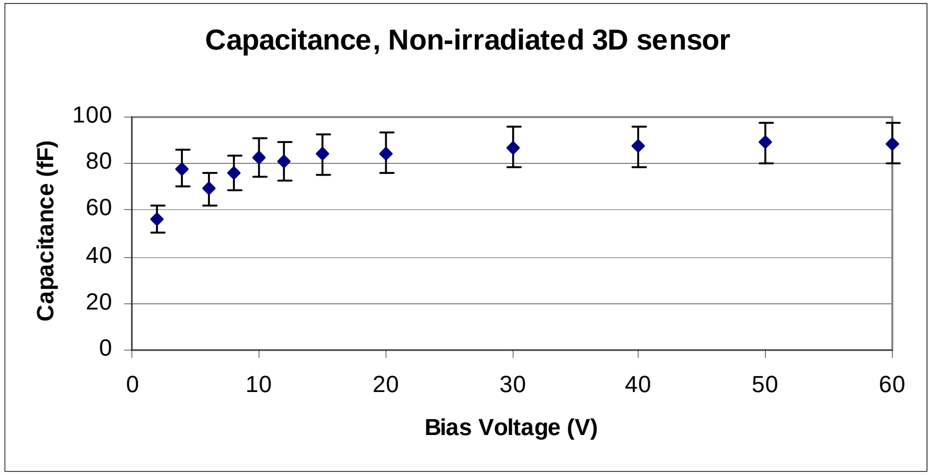




- RC Time Const = $R*(C+C_{3d})$= 169nS
- **$C_{3D}$ = 85fF**

# Electrode Capacitance, indirect meas.

- Indirect Measurement using Decay Time of signal on Picoprobe,
- Non-irradiated p-electrode
- Average RC time constant is 169nS, p-electrode capacitance is 85fF



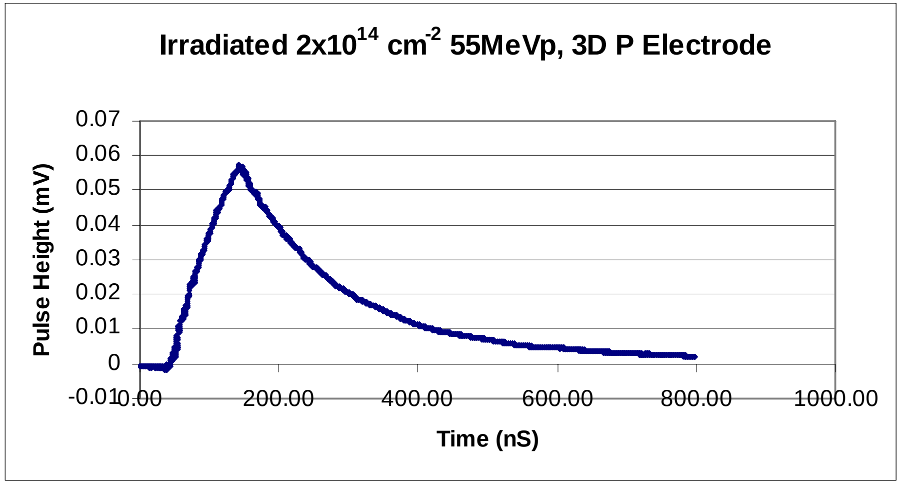



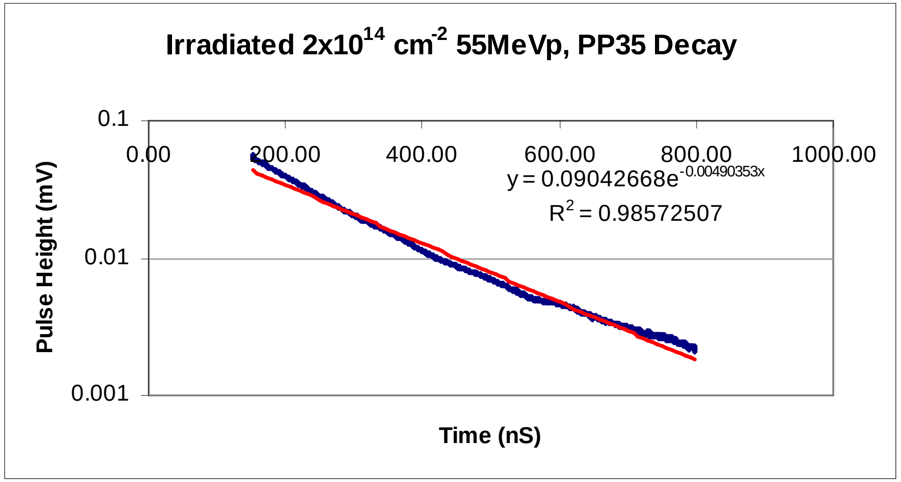



Martin Hoeferkamp,UNM

# Electrode Capacitance, indirect meas.

- Indirect Measurement using Decay Time of signal on Picoprobe 35, Irradiated sensor p-electrode




* On irradiated sensors there is a long tail at longer times which may be due to release of charge from traps produced by irradiation.

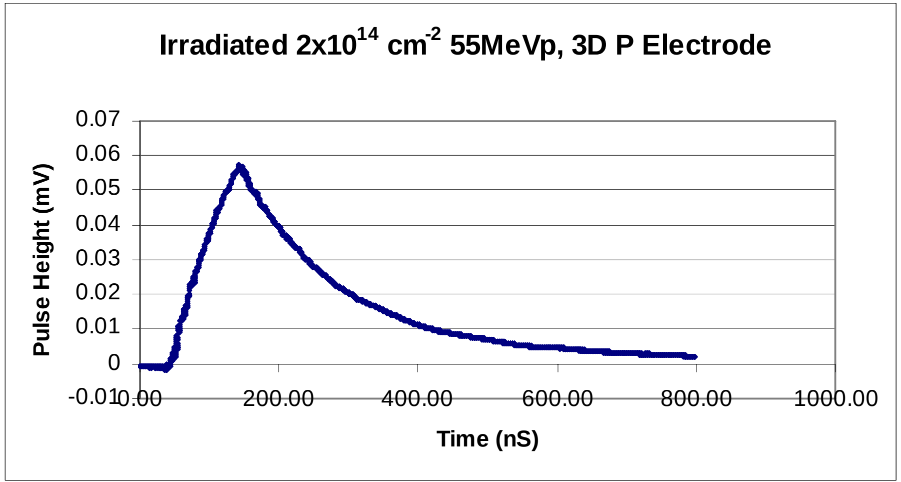
- Assuming a single dominant trapping time constant $\tau$:

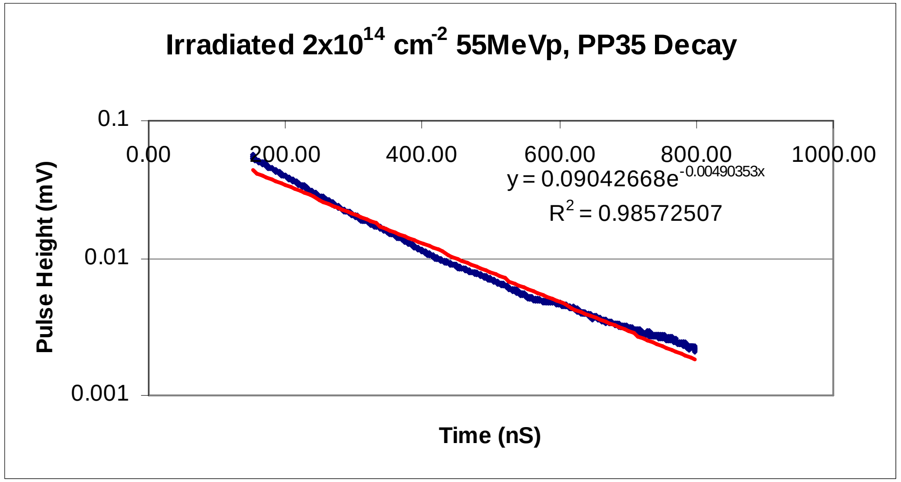
$$V = [V_o - V_{\tau o}(RC/\tau - RC)]e^{-t/RC} + V_{\tau o}(RC/\tau - RC)]e^{-t/\tau}$$

(Ref: S. Parker and C. Kenney, IEEE Trans. Nuc. Sci. ,Vol. 48, No. 5, Oct. 2001)

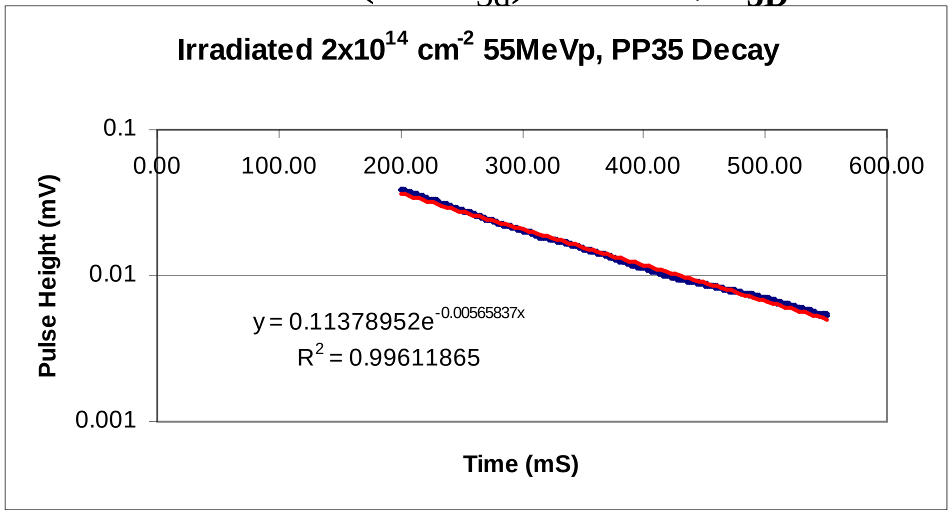
# Electrode Capacitance, indirect meas.

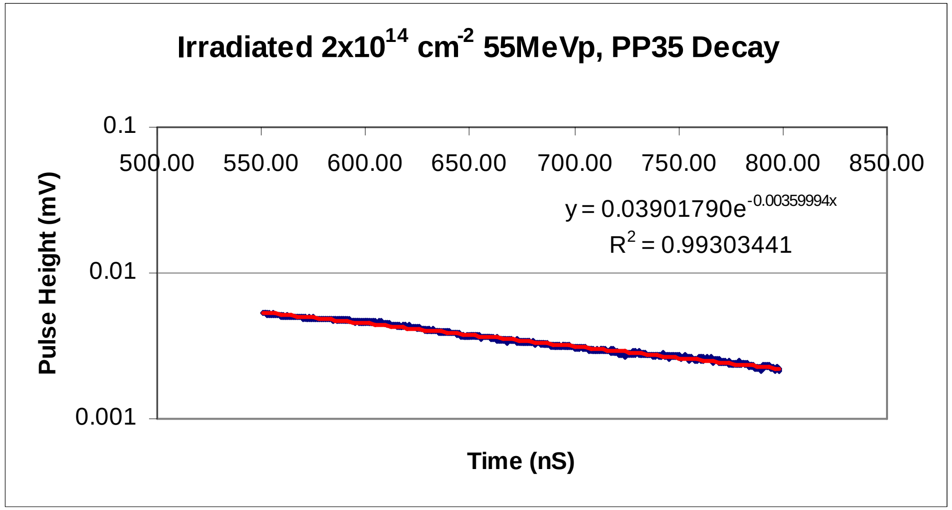
- Indirect Measurement using Decay Time of signal on Picoprobe 35, Irradiated sensor p-electrode



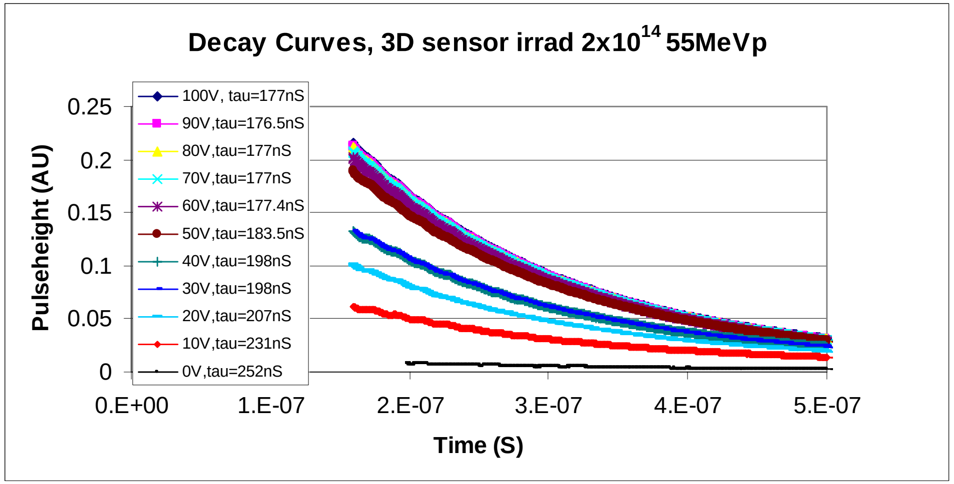

Time Const=R*($C+C_{3d}$)=177nS,**$C_{3D}$=91.6fF** **Second time const = 273nS**

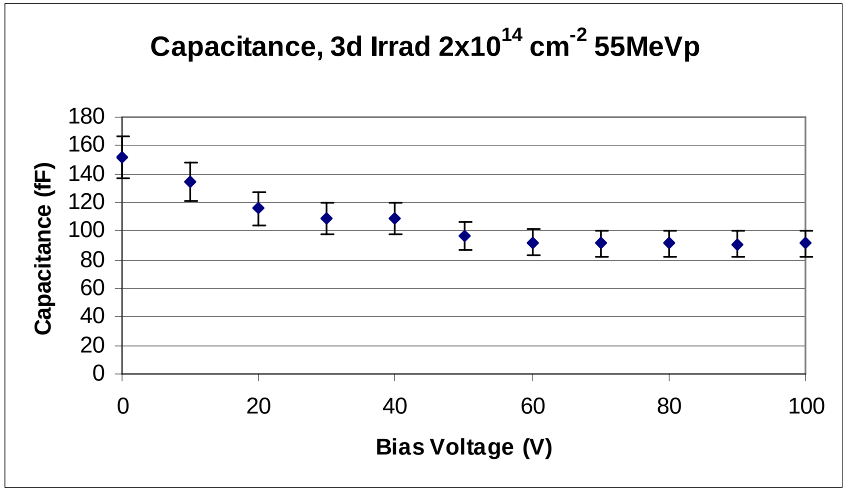


# Electrode Capacitance, indirect meas.

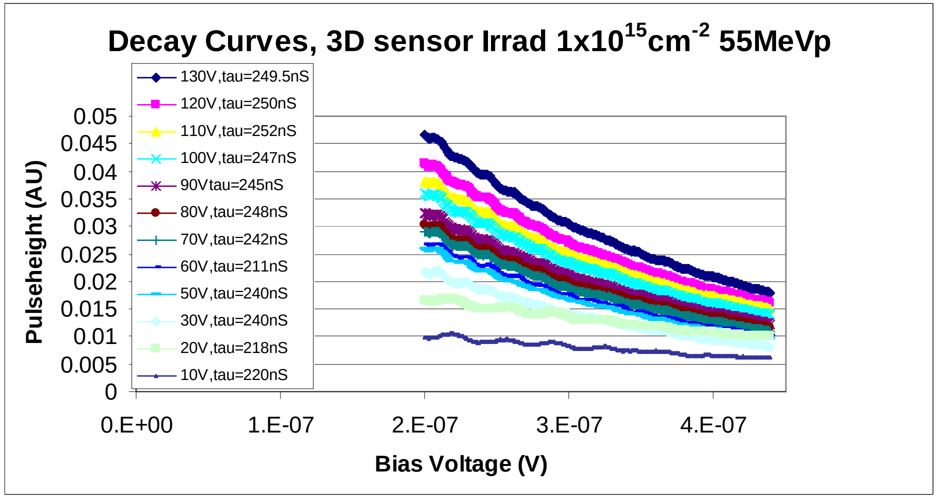
- Indirect Measurement using Decay Time of signal on Picoprobe
- Irradiated $2x10^{14}$ $cm^{-2}$ 55MeVp sensor p-electrode
- Average RC time constant is 177nS, p-electrode capacitance is 91.6fF
- Second (trapping?) time constant $\tau$ is 273nS

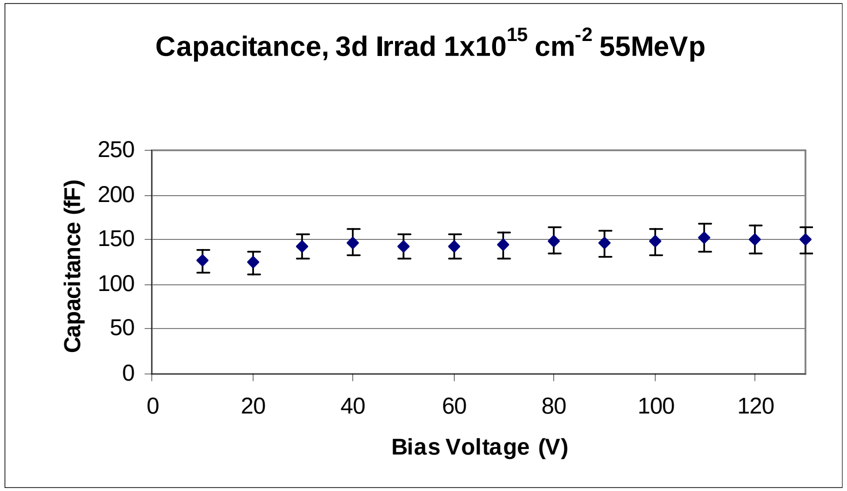


# Electrode Capacitance, indirect meas.

- Indirect Measurement using Decay Time of signal on Picoprobe
- Irradiated $1x10^{15}$ $cm^{-2}$ 55MeVp sensor p-electrode
- Average RC time constant is 247nS, p-electrode capacitance is 147fF
- Second (trapping?) time constant $\tau$ is 373nS



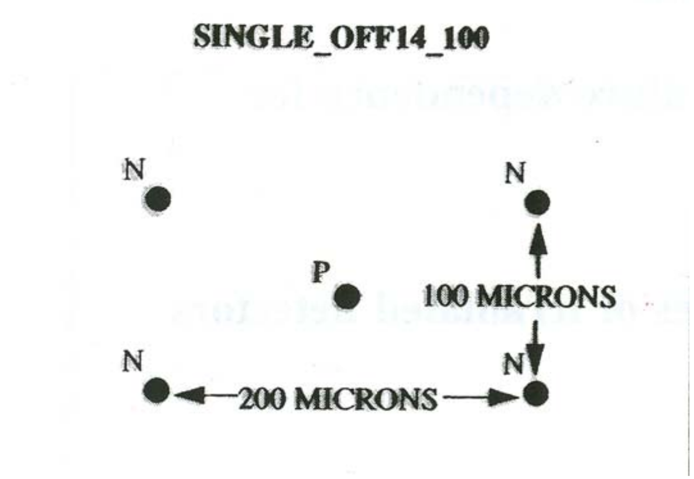



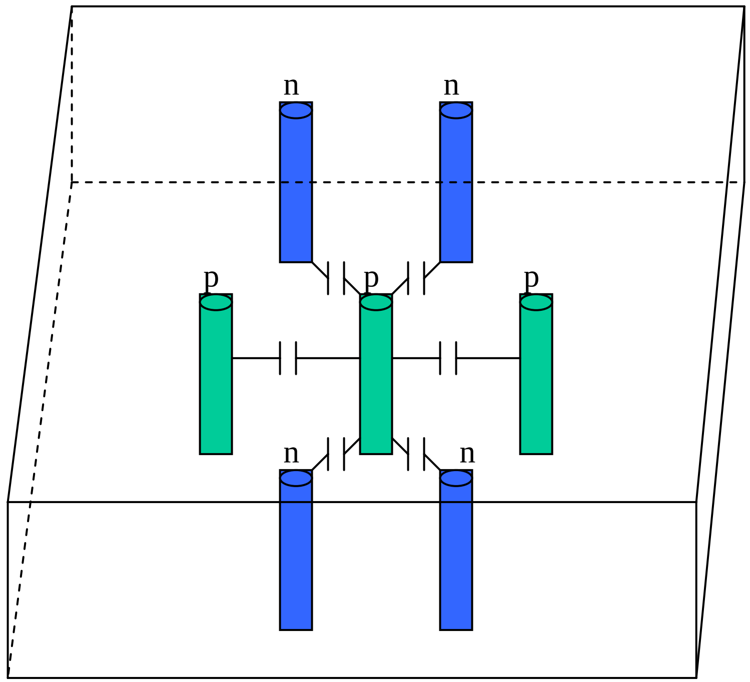



Martin Hoeferkamp,UNM

# Electrode Capacitance, calculation

- 3D Electrostatic Calculation (IES Coulomb):
  - P Electrode Length = 120 um
  - P Electrode Diameter = 20 um
  - Center electrode to nearest neighbors




**Result:**
**3D calculation $C_{3D}$ P electrode = 31fF**
**Note: result verified by S. Watts (Brunel U.) using an alternative calculation.**

# Comparison of Results

- Summary: Indirect measurement gives similar results to 10KHz LCR meter result

| | Non-Irrad | Irrad 2x$10^{14}$ | Irrad 1x$10^{15}$ |
|---|---|---|---|
| LCR meter 10KHz, P electrode | **71 fF** | **96 fF** | **98 fF** |
| LCR meter 100KHz, P electrode | 58 fF | 69 fF | 70 fF |
| LCR meter 1MHz, P electrode | 46 fF | 53 fF | 55 fF |
| Indirect Measurement, P electrode | **85 fF** | **92 fF** | **147 fF** |
| 3D calculation, P electrode | 31 fF | | |

# Summary

- Two methods for measuring 3D sensor capacitance and results are presented.

- In general the indirect method gives similar results to the direct method with the LCR meter frequency of 10KHz. This is also consistent with the RD50 guideline of 10KHz LCR measurements.

- 3D sensor Electrode Capacitance depends on frequency of the LCR meter and on the sensor temperature, same as for planar sensors.

- Need to further investigate possibility of extracting the trapping time constant from the second time constant of the irradiated sensors.