Measuring Linearity of Detector Spectral Responsivity at Ultra-Low Incident Powers

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Agenda

- Background and Motivation
- Testing condition, setup and procedure
- Test results and analysis
- Discussion

Background

- Next-generation scatterometer development is underway at NASA/GSFC Code 618 Diffuser Calibration Lab (DCL)
- The detection system for scatterometer need to be characterized to meet the system requirements, including, but not limited to:
  1. Electronic Signal to Noise Ratio (S/N)
  2. Dynamic Range (4~5 magnitude orders)
  3. Non-Linearity from the pre-amp
  4. Non-Linearity of the detector spectral responsivity
  5. Etc.

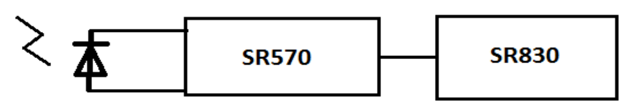
Background

- The detection system works in AC-mode, and includes a New Focus 3502 optical chopper, a Stanford SR570 pre-amp, a Stanford SR830 lock-in amplifier and a set of detector heads
- The detectors* under test are:
  A. Si: S2281-04 s/n: 4G001 (190 nm ~1100 nm)
  B. Std-InGaAs: G12180-250A s/n: 45 (900 nm ~ 1700 nm)
  C. Ex-InGaAs: G12183-230A s/n: 251 (900 nm ~ 2500 nm)

*Products from Hamamatsu

Background

- The SR-570 pre-amp has a gain range from 1.0E+3 to 1.0E+12, and a maximum output ±5 Volt;
- The SR-830 is a DSP lock-in amplifier has a maximum input 1 Volt.
- The photon current from the detector was fed to the SR570 directly, and converted to voltage, then passed to SR830 as shown below.



Background

- To measure the non-linearity from pre-amp, we set the light source to a fixed level, and its stability is monitored by a NIST linearity-characterized detector; by changing the pre-amp's gains, we recorded the signal changes. The signal from the monitoring detector was used to correct any changes caused by the light source. This work was done and documented in a 2015 SPIE San Diego proceeding "Characterization and Application of a LED-driven Integrating Sphere Source"(Proc. Of SPIE Vol. 9607 96070Y-1)
- To measure the responsivity non-linearity from the detector, we set the pre-amp's gain to a fixed value, say 1.0E+8. By changing the output level of the light source, we recorded both signals from the monitoring detector and the detector under test. The signal from the detector under test compared to the signal from linearity-characterized detector. This way, the spectral responsivity linearity of the detector under test was characterized.

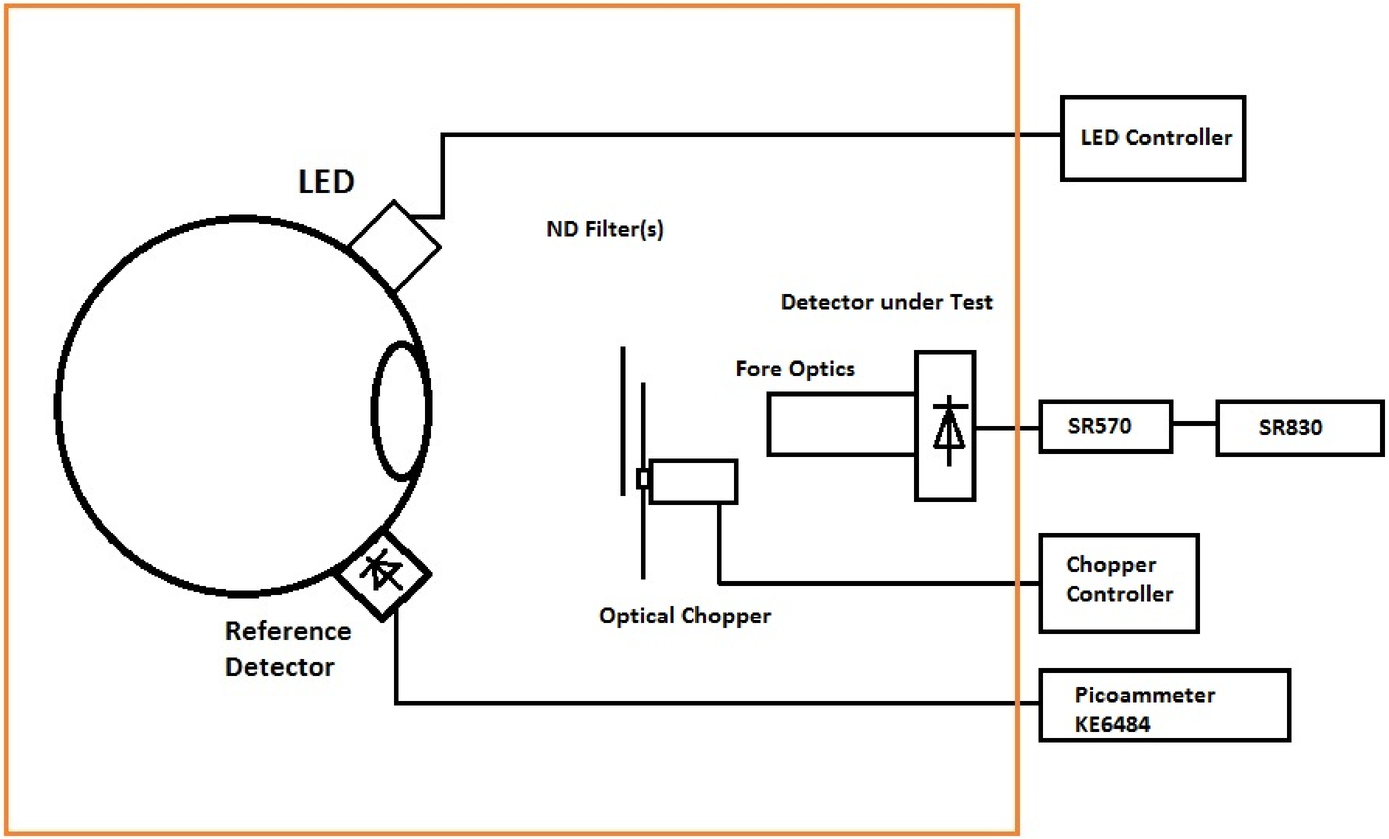
Motivation

- While I was measuring the responsivity non-linearity from different detectors, two of the questions popping up were “how low of an incident power can the detection system detect, and how linear is the spectral responsivity of the detector under such low incident power?
- This work mainly focuses on answering these two questions.

Challenges

- To successfully make those measurements, some conditions need to be fulfilled
  1. Absolutely no stray light and ambient light
  2. The light source needs to be very stable under such low power levels
  3. The power level of the light source can be easily adjusted

Test setup


LED Controller
LED
ND Filter(s)
Detector under Test
Fore Optics
SR570
SR830
Chopper Controller
Reference Detector
Optical Chopper
Picoammeter KE6484

Light-Tight Enclosure

Uniform Light Source

- Integrating sphere 30.5 cm (12”) in diameter
- Lined with Spectralon
- 10 cm (4”) opening
- 4 ports for mounting LEDs
- 2 ports for mounting monitoring detectors

Component Description--LED

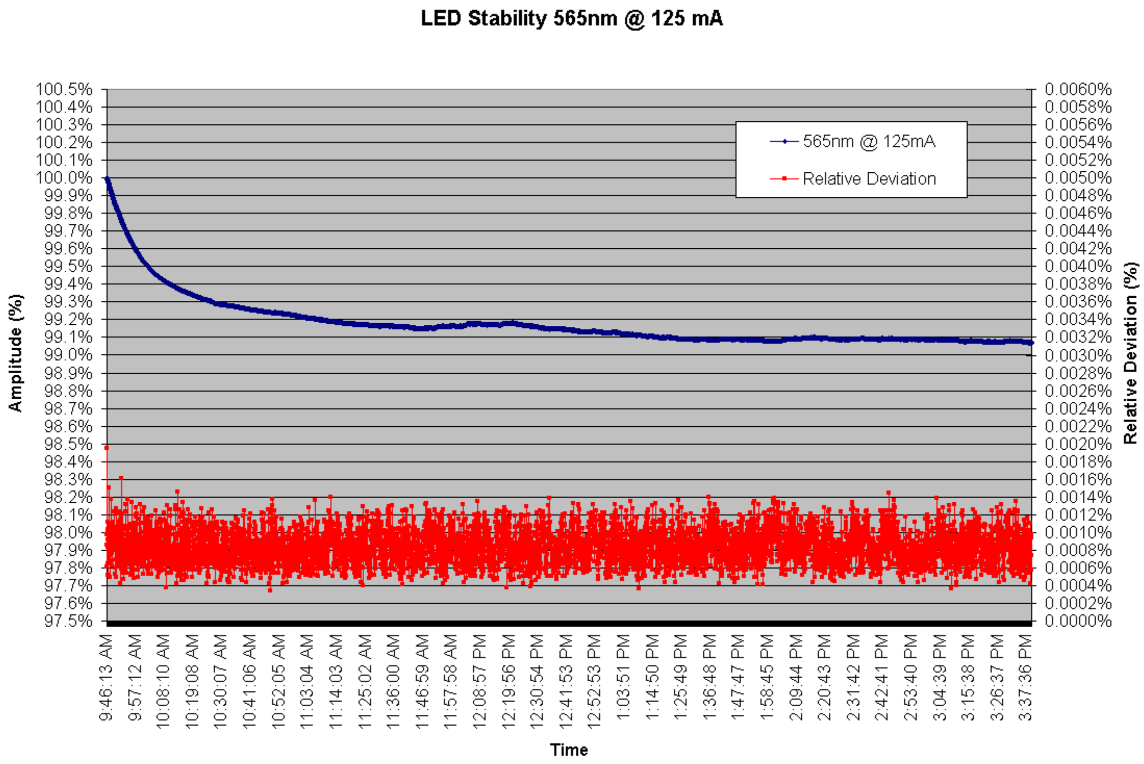
- Off-the-shelf products from Thorlabs.com
- A wide range choice
- Relatively narrow spectral band-pass
- Relatively high power output
- Work under constant current mode, easy to control and stable

Component Description--LED

	Si					InGaAs			
Wavelength	405 nm	565 nm	730 nm	850 nm		1200 nm	1300 nm	1450 nm	1550 nm
FWHM	20 nm	100 nm	30 nm	30 nm		80 nm	80 nm	80 nm	102 nm
Max Power	760 mW	150 mW	310 mW	450 mW		30 mW	25 mW	31 mW	31 mW
Adjustable Current	0~1000mA	0~500mA	0~1000mA	0~1000mA		0~700mA	0~500mA	0~700mA	0~1000mA

Component Description--LED

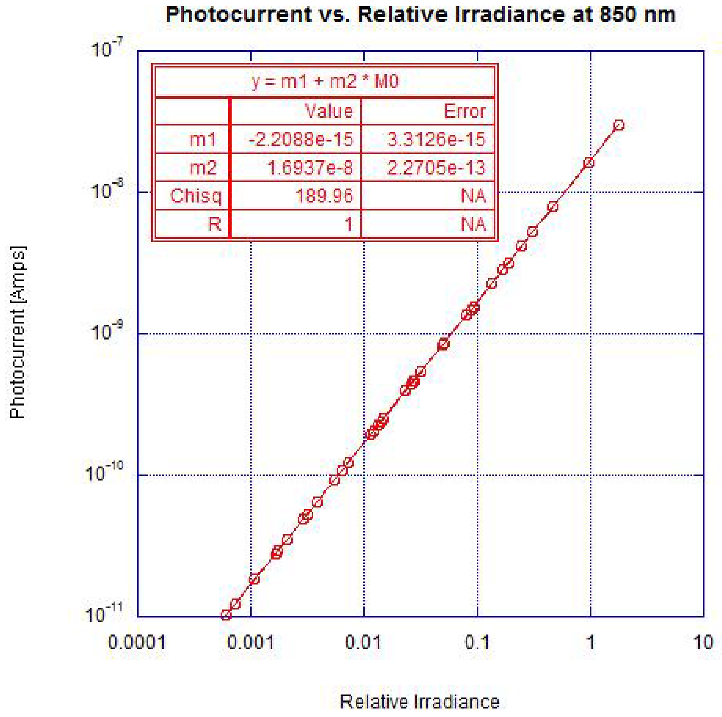
- Stability of the LED output was measured by the mounted monitoring detector
- The fluctuation level is less than 0.1% after half hour warm up

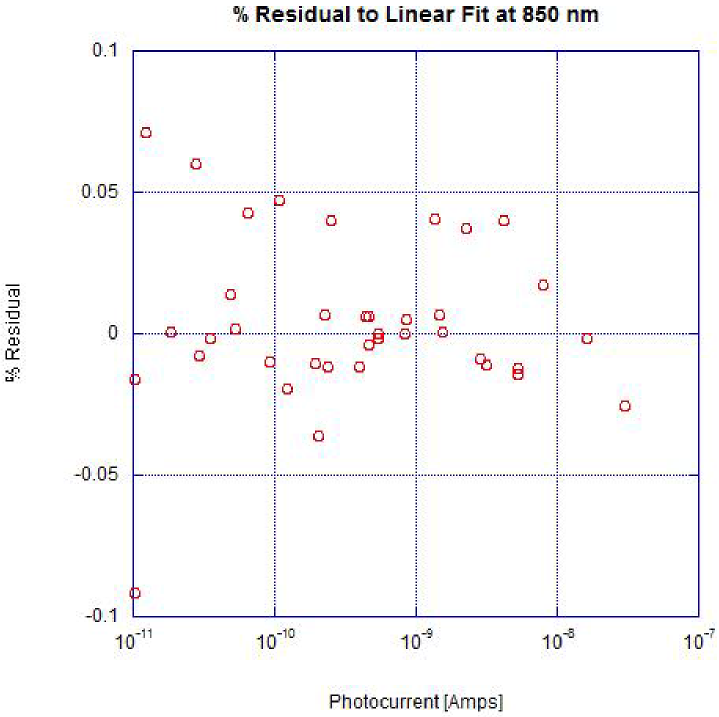


Component Description—Monitoring Si Detector

- Hamamatsu S2592-03 UV Enhanced Si Detector
- Spectral range 190 ~ 1100 nm
- 2.4X2.4 mm^2 active area
- TE cooled to -10^0 C
- Secured in aluminum socket for heat dissipation, set-screw mounted to the detector port on sphere

Component Description—Monitoring Si Detector





Component Description—Monitoring Std-InGaAs Detector

- Hamamatsu G12180-230A standard InGaAs detector
- Spectral range 900 nm ~ 1650 nm
- Ø 3.0 mm active area
- TE cooled to -20^0 C
- Secured in aluminum socket for heat dissipation, set-screw mounted to the detector port on sphere

Component Description—Monitoring Std-InGaAs Detector

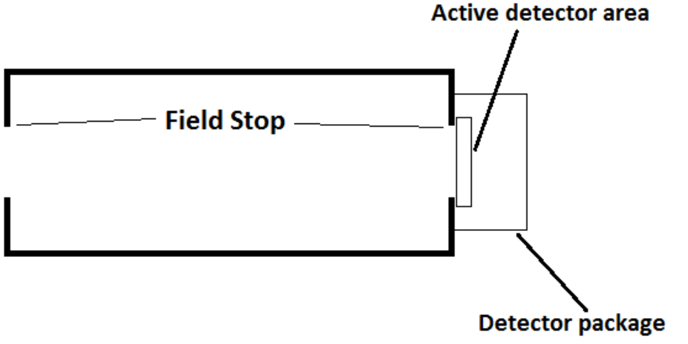
- This detector was characterized for spectral-response-linearity by NIST using their Beamconjoiner Apparatus under those four IR wavelengths
- The photon current range in the NIST characterization was from 10^{-6} ~ 10^{-11} amperes
- The measured non-linearity was within 0.1% in the 10^{-6}~10^{-10} ampere photon current range
- The measured non-linearity was within 0.5% in the 10^{-10}~10^{-11} ampere photon current range

Component Description-Detectors under Test

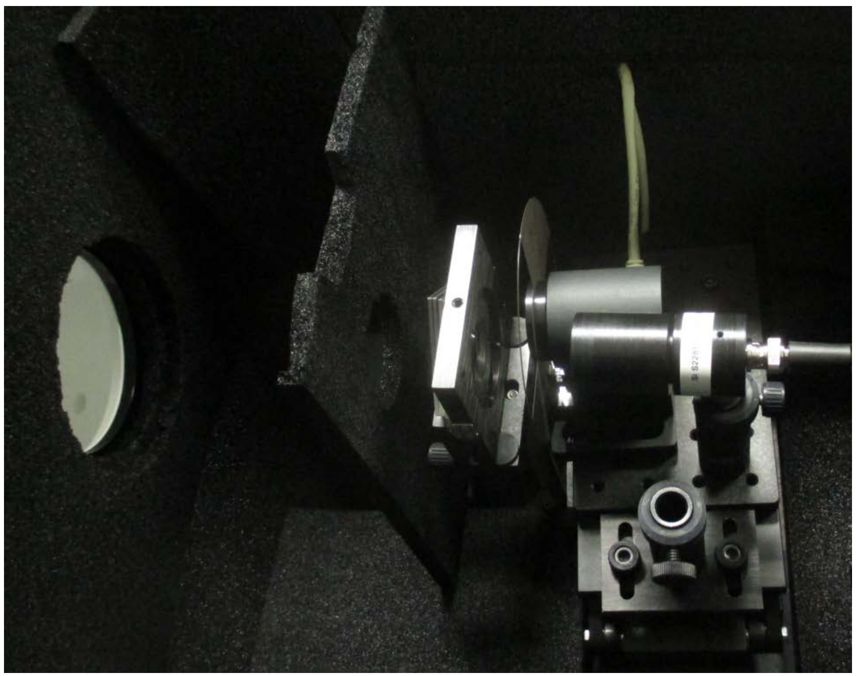
	Si	Std-InGaAs	Ex-InGaAs
Model #	S2881-04	G12180-250A	G12183-230K
Active Area (mm)	Ø7.98	Ø5.0	Ø3.0
Spectral Range (nm)	190~1100	900~1650	900~2550
TE temp (C^0)	Room	-20	-20
Shunt Resistance (MΩ)	200	500	0.028
Terminal Capacitance (pF)	1300	1000	3200
NEP ($W/Hz^{1/2}$)	$1.8X10^{-14}$	$5.3X10^{-15}$	$6X10^{-13}$

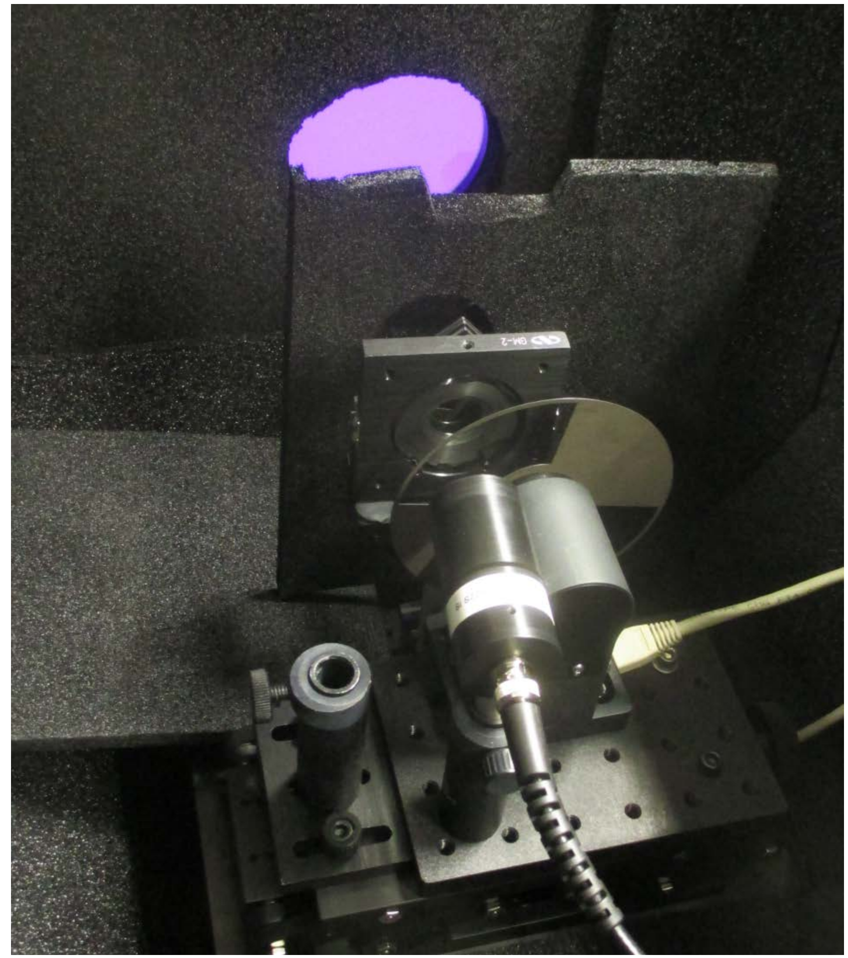
Fore Optics

- The fore optics were configured in radiance mode to accommodate the situation in the BRDF measurements.
- Black Delrin was used to make the fore optics.
- This configuration was used for preliminary measurement purpose only, the final configuration will include a lens



Inside the Light-Tight Enclosure





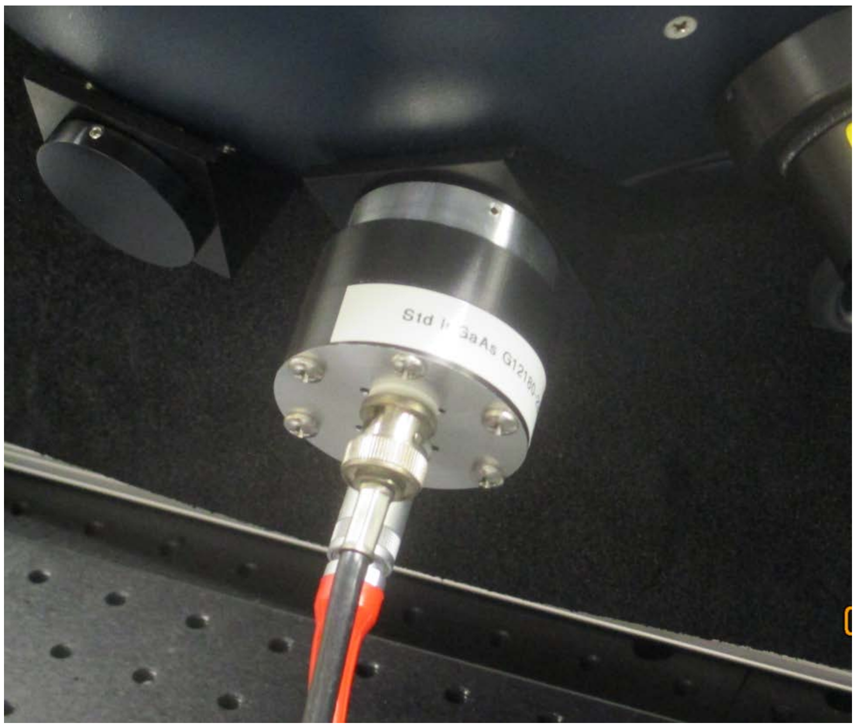
Measurement Procedure

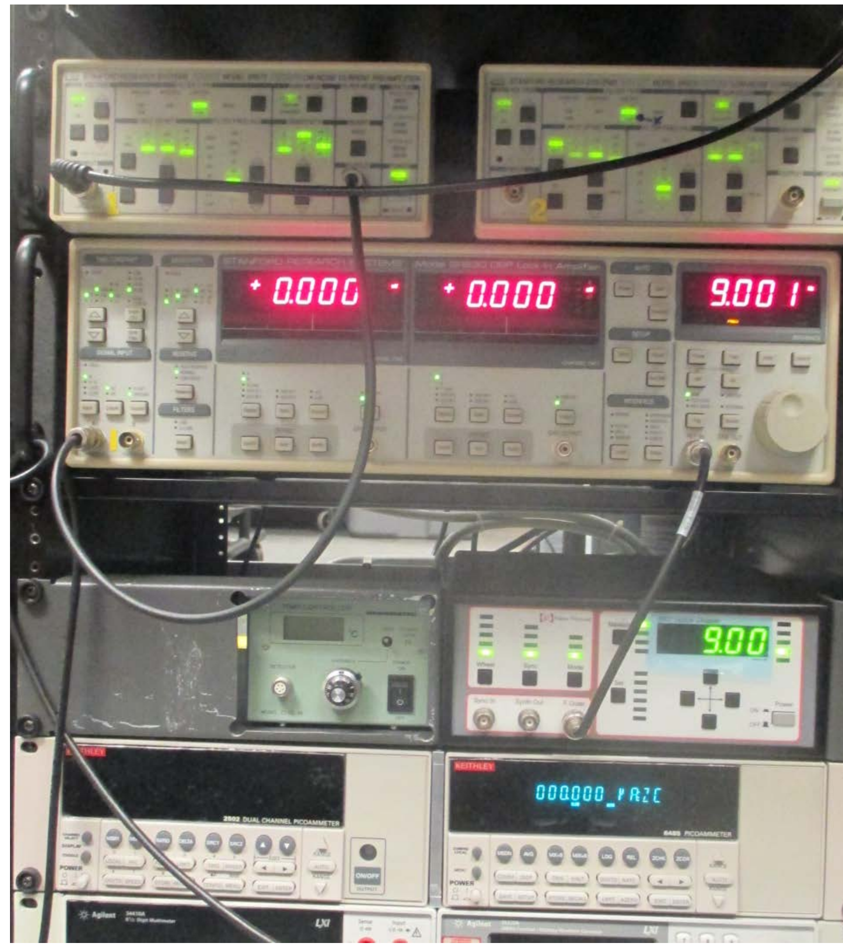
- Set up all the components inside the light-tight enclosure;
- Determine the highest gain that the SR-570 pre-amp can be used with each detector;
- With the highest gain set in the SR-570, and the lowest LED current set in the LED controller (usually is 1 mA), put one or more ND filters in front of the fore optics so that the output of lock-in amplifier SR-830 is close to the noise floor of the whole electronic system (or dark signal, around 1 μV);
- Gradually increase the LED controller's output current, record the output from SR-830 and the monitoring signal from KE6485
- Use the monitoring signal as reference to compare the output from SR-830, draw the linearity fitting function and calculate the linearity fitting error

Benefits of This Procedure

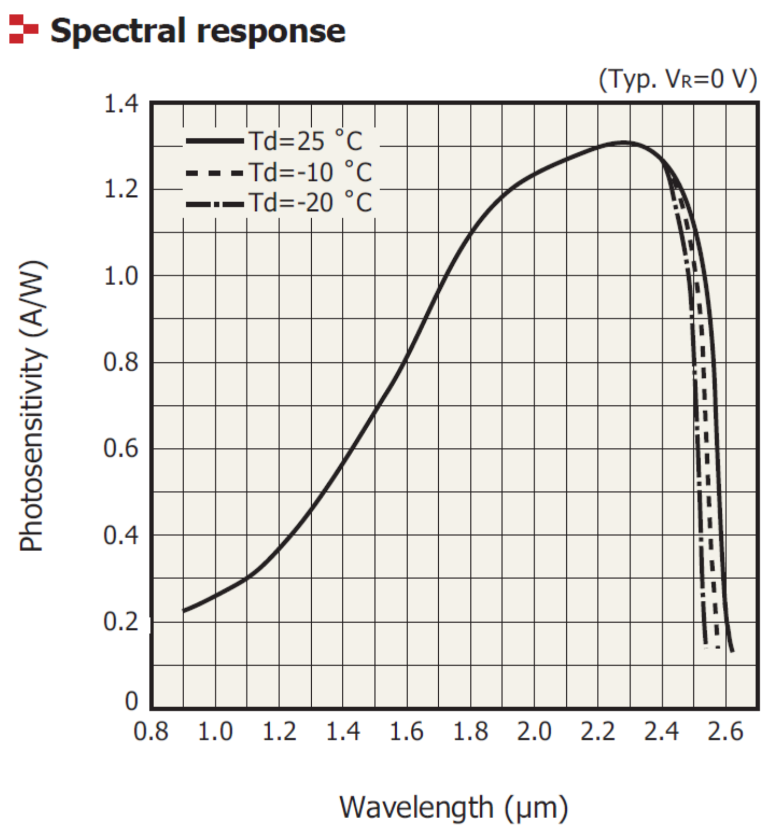
- The measurement results won't be affected by stray light or ambient light due to the light-tight enclosure;
- The integrating sphere can reduce the output level greatly while the LED source maintains its stability;
- The ND filters provide even more flexibility to drop the light level that finally enters the fore optics and reaches the detector active area;
- They also make sure the monitoring detector is working in the light level in which it was characterized, while the detector under test is working in the much lower light level.

Instrument and Set up



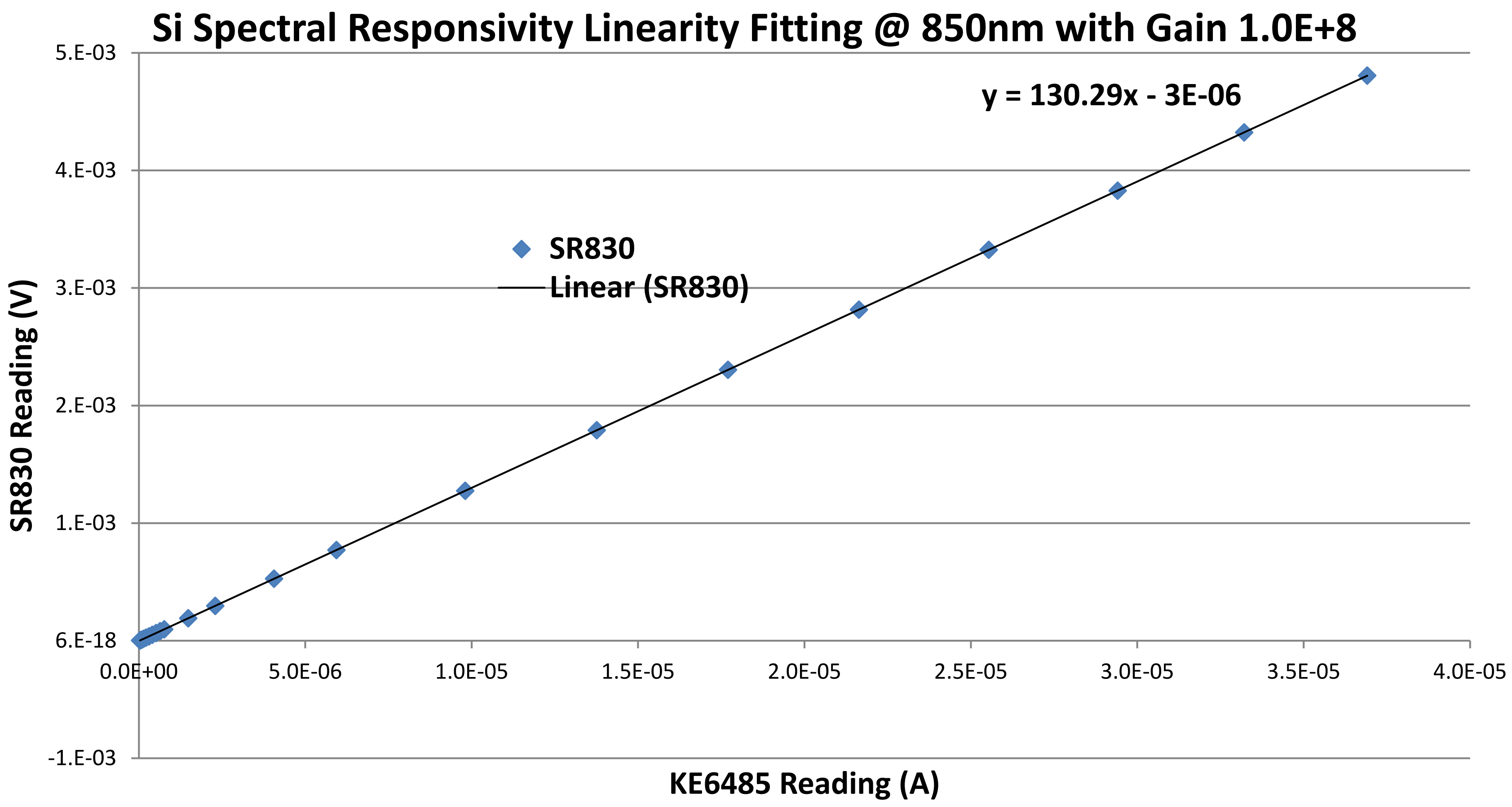


How to Estimate Incident Power

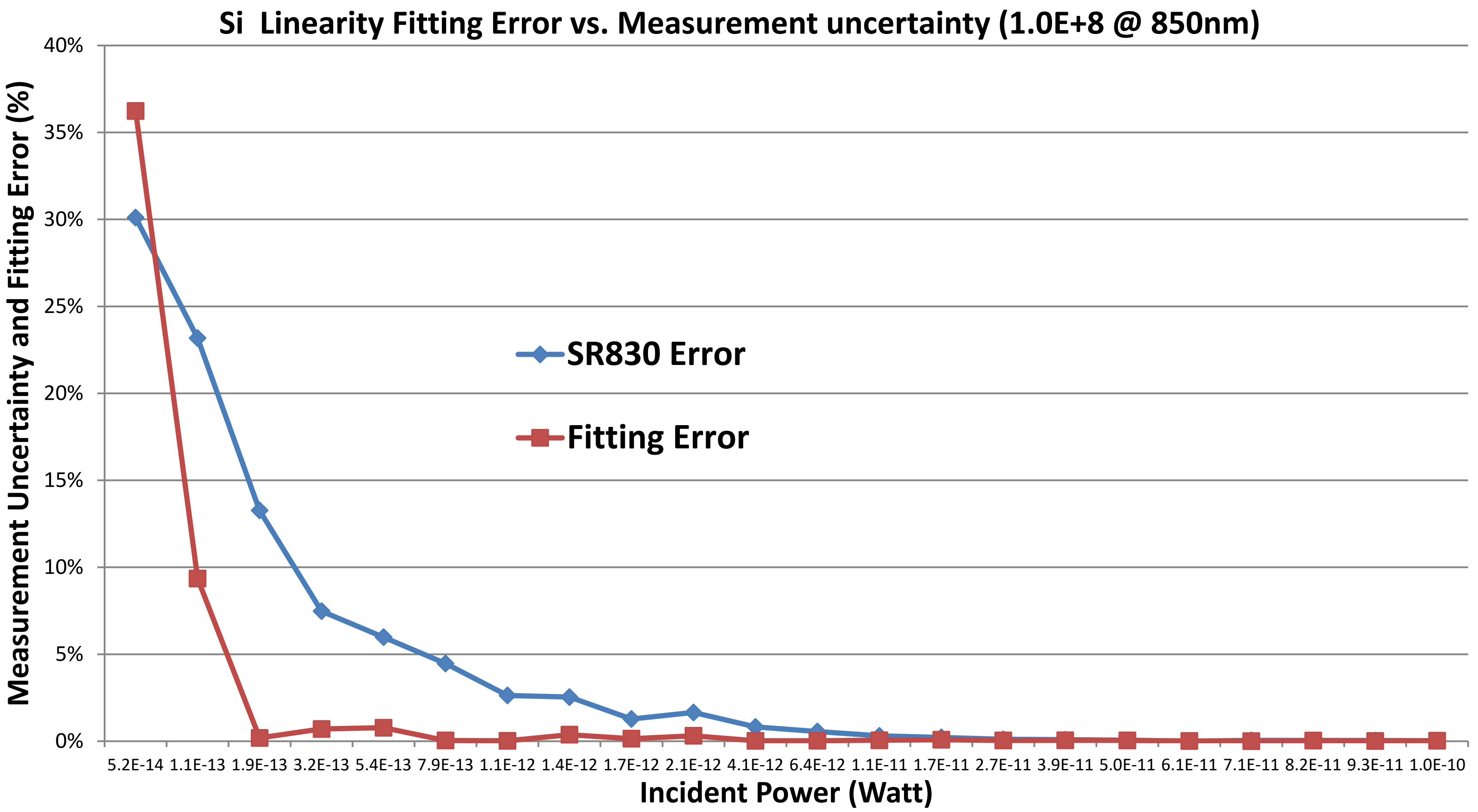


- Use Ex-InGaAs G12183-230K as an example. Left chart shows its spectral response.
- At 1550 nm, its photosensitivity is about 0.75A/W.
- If the Lock-in SR830 readout is 10 μV with 1.0E+06 gain for pre-amp SR570, the incident power is estimated as $10 \div (10^6 \times 10^6) \div 0.75 = 13.3pW$

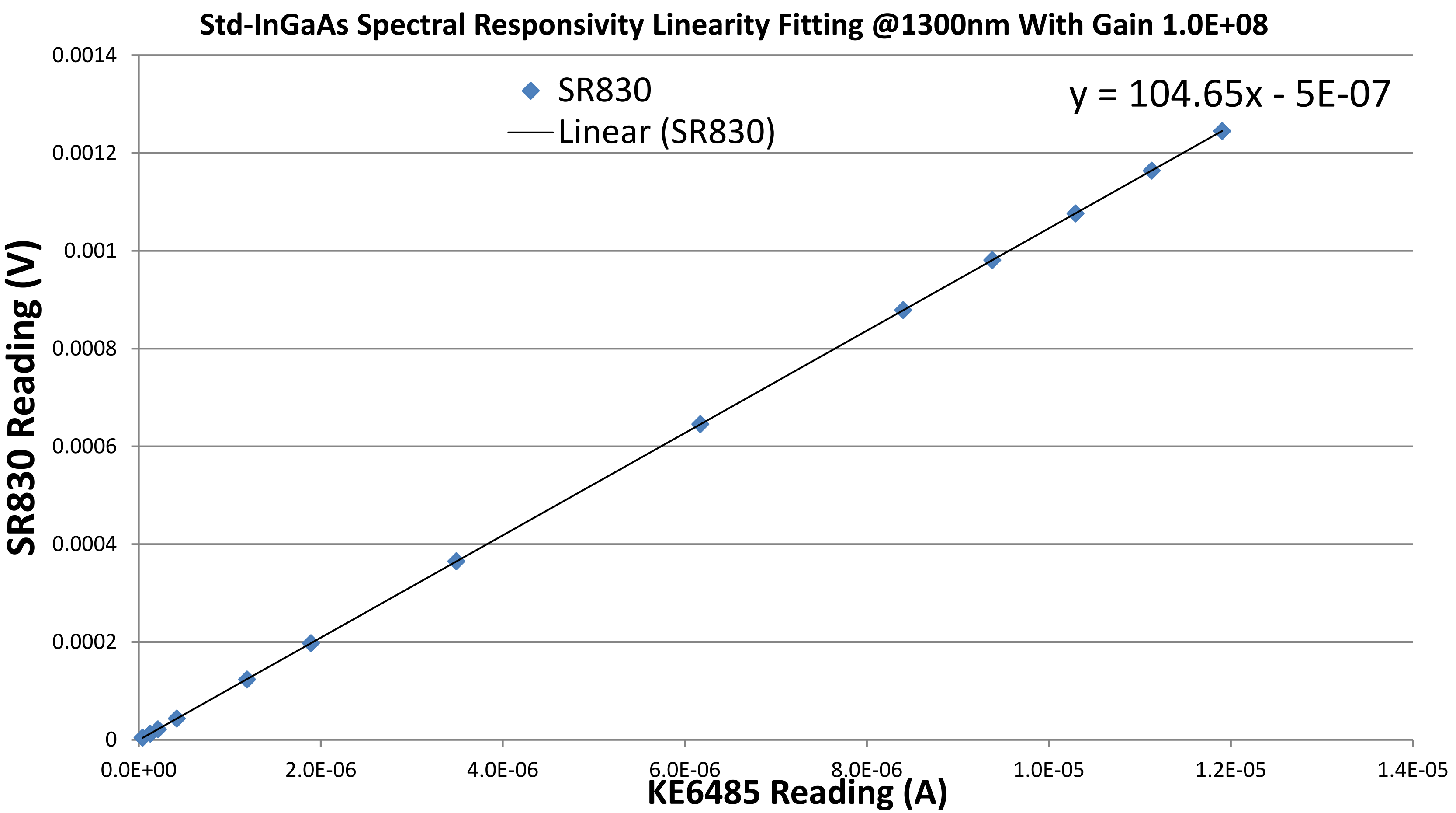
Some of Test Results--Si



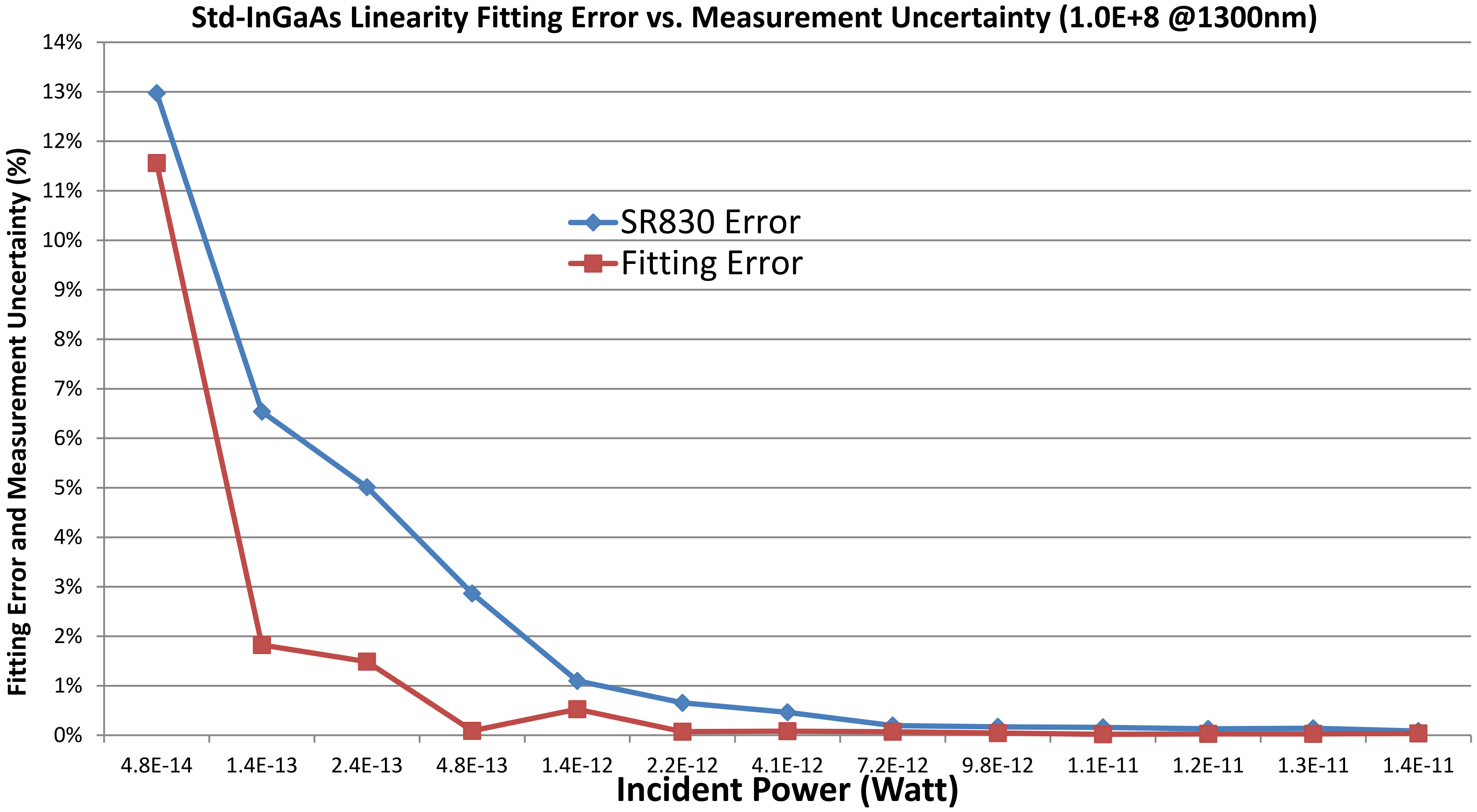
Some of Test Results -- Si



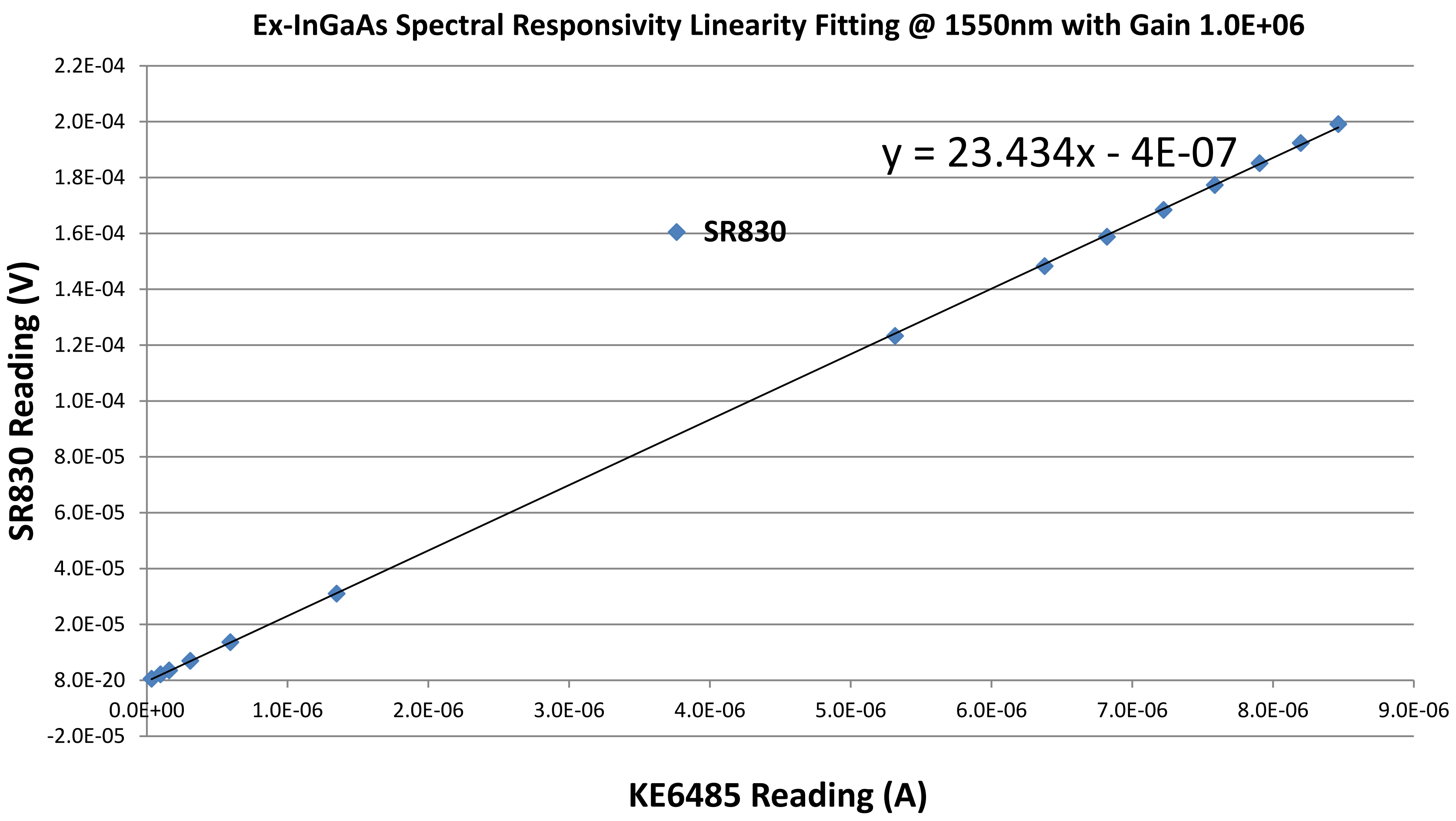
Some of Test Results – Std-InGaAs



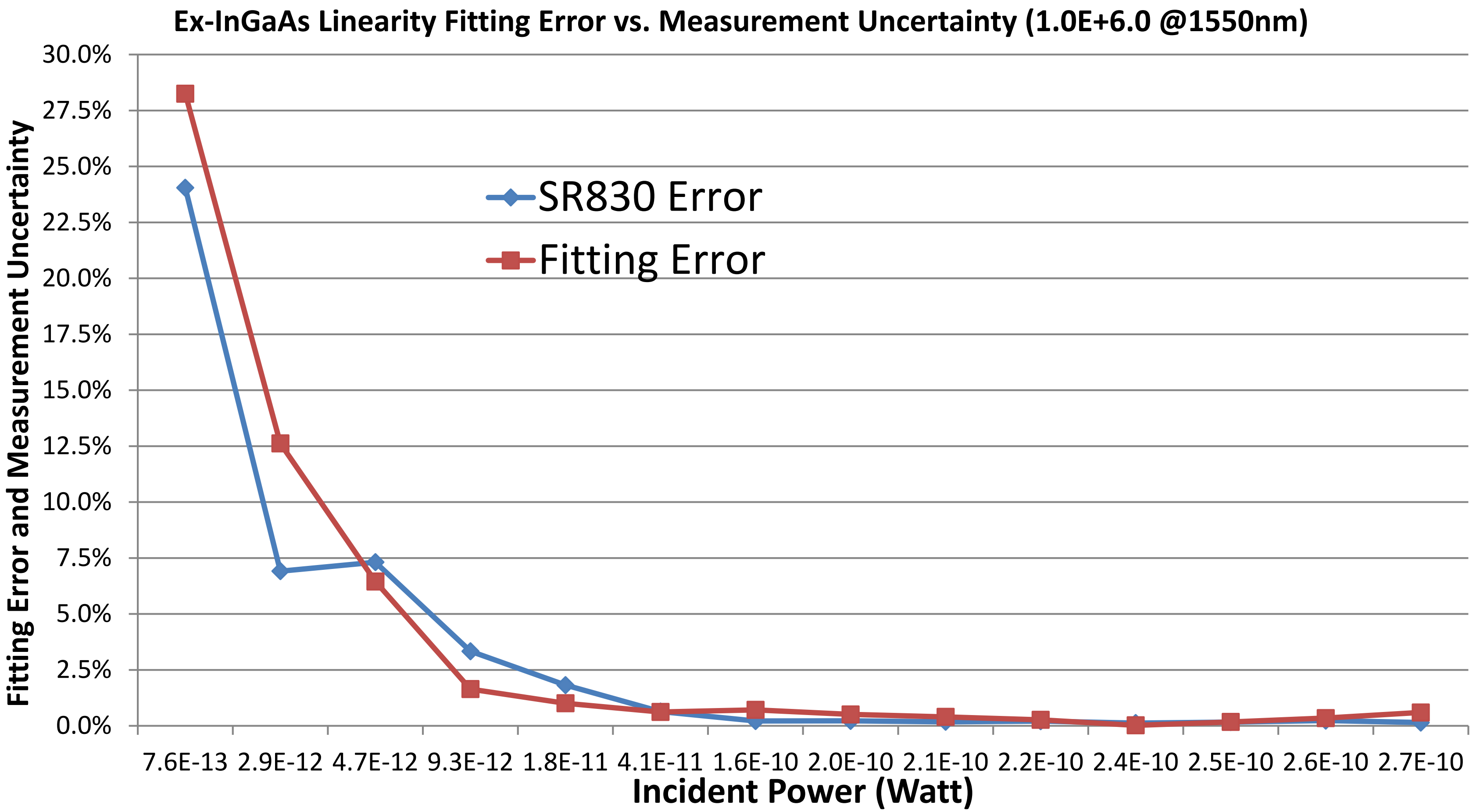
Some of Test Results – Std-InGaAs



Some of Test Results – Ex-InGaAs



Some of Test Results – Ex-InGaAs



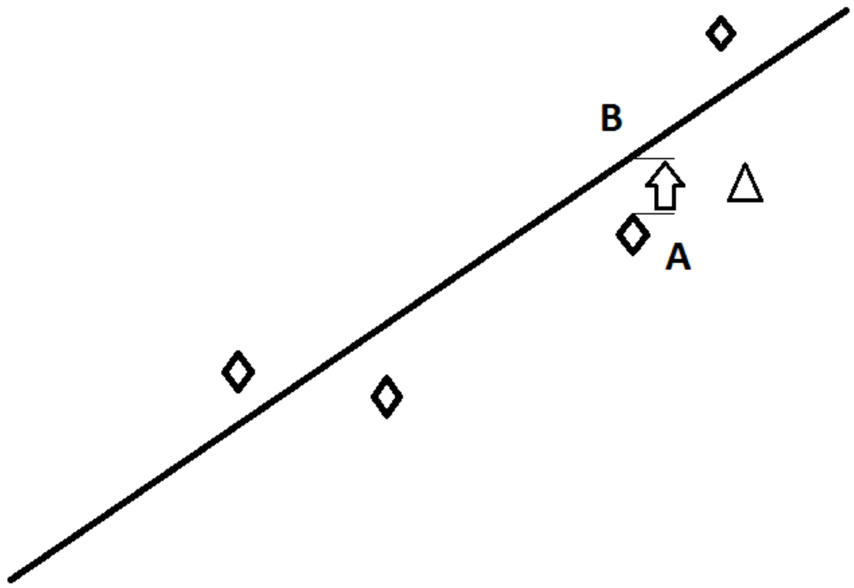
Results Analysis

- The tests present results where the incident powers are getting very close to the NEP (Noise Equivalent Power) of each detector;
- The linearity fitting error is getting higher while the measurement uncertainty is getting worse;
- But that does not mean the response linearity is getting worse when the incident power drops close to detector’s NEP.

Results Analysis

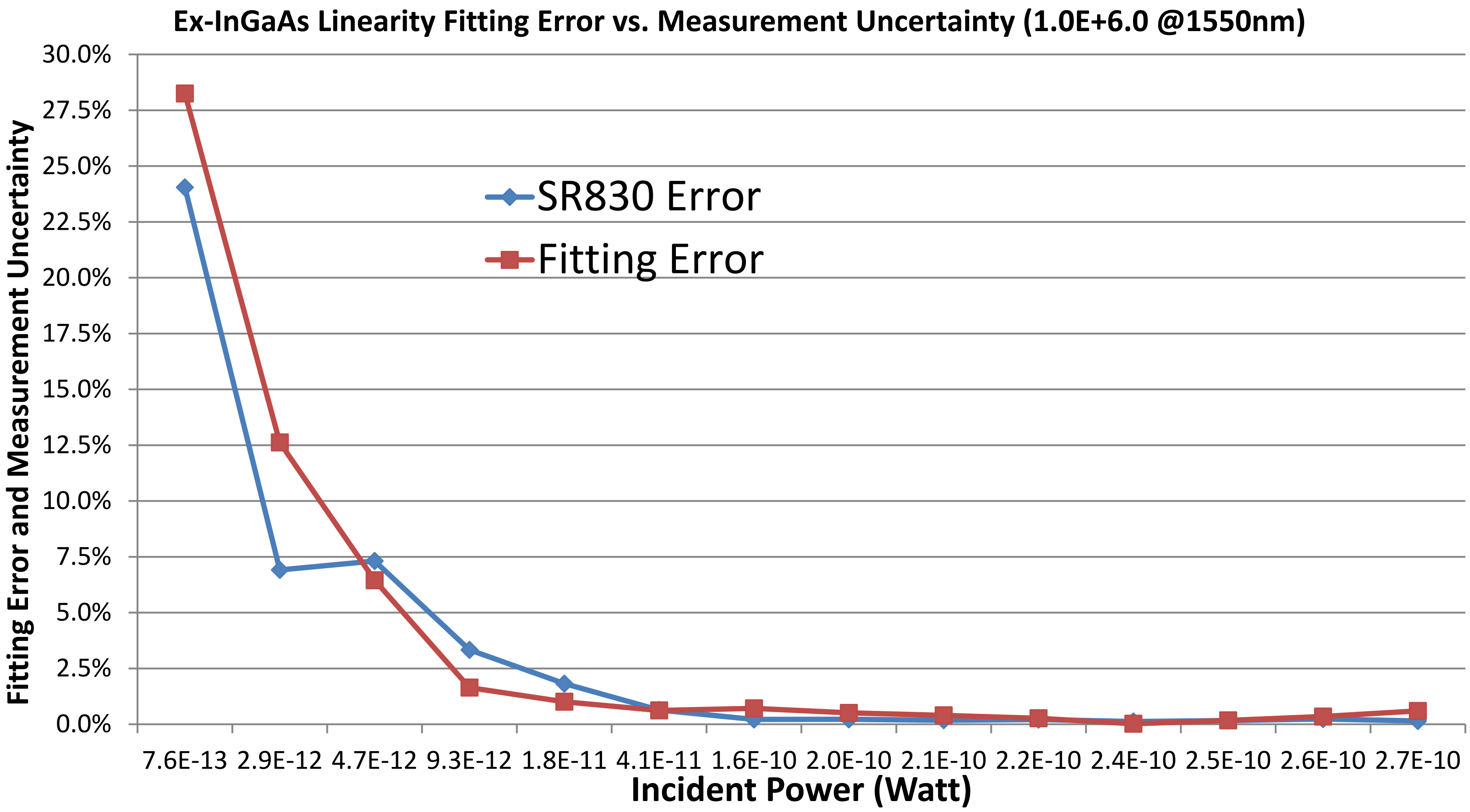
- The higher measurement uncertainty close to NEP level can surely contribute to the higher fitting error
- The fitting error calculation method also makes a big contribution to the higher fitting error when the incident power is close to the NEP level

Fitting Error Analysis

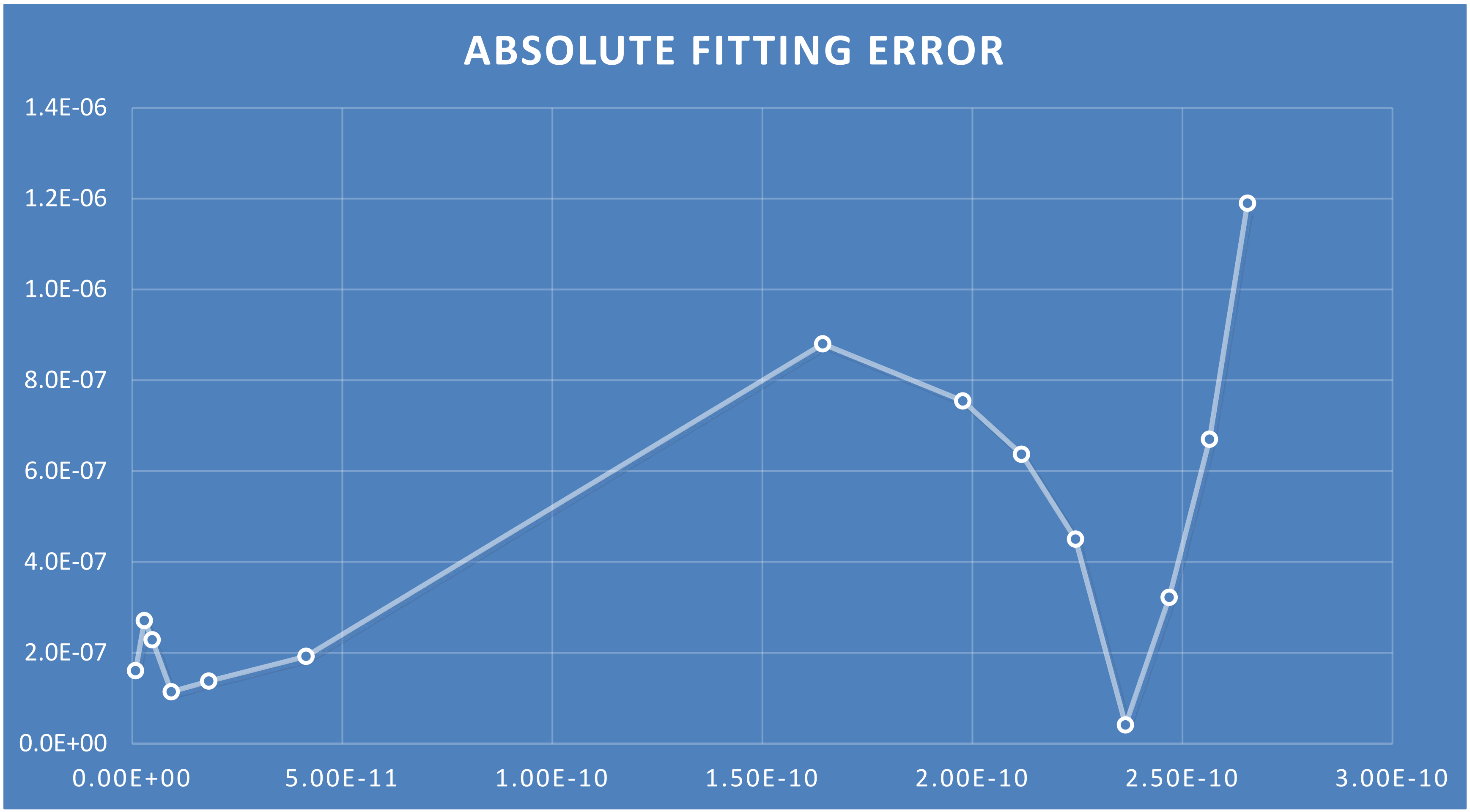


- Using Δ to represent the absolute fitting error in my case, the fitting error shown in the chart was calculated by Δ/(Value B), or say relative fitting error.
- The fitting program will try to make the sum of all the Δ^2 minimum, which will cause the uniform distribution of Δ^2.
- When the Value B gets smaller and smaller, it will make the relative fitting error bigger and bigger.

Look Back at the Ex-InGaAs



Look Back at the Ex-InGaAs



Summary

- The measurements at the power levels that are close to the detector's NEP level can be performed and the results show that at such low incident power levels, the spectral responsivity of different detectors maintains linear.
- We also are interested in testing the detectors' linearity of responsivity at very high incident power levels, to find out the power limits and the power density limits that can cause the detector to saturate.

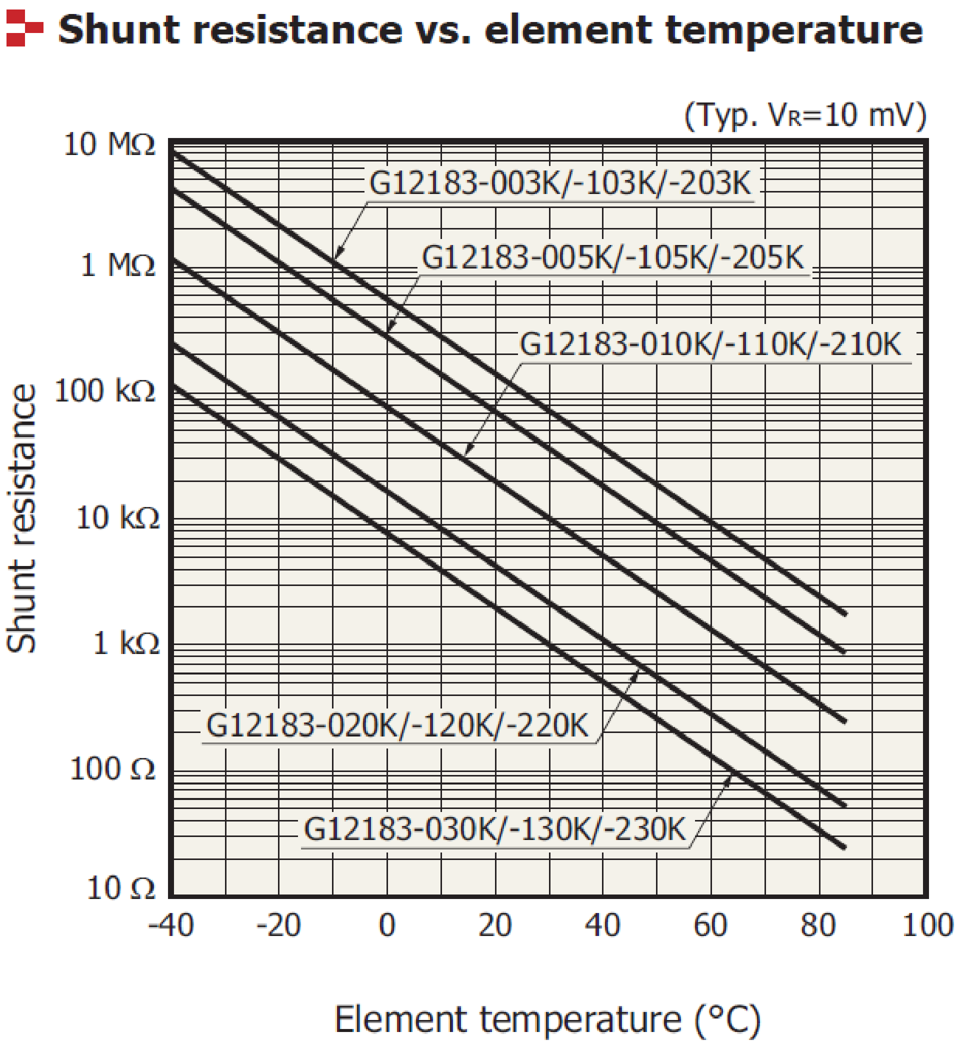
Thanks for Attending

Q&A
Comments

Backup

- Two factors to determine the highest gain that can be used in the pre-amp:
  1. The shunt resistance of the photodiode detector
     1. The pre-amp gain setting requires that the highest gain can not be set to be higher than the detector's shunt resistance
     2. Terminal (PN junction of detector) temperature makes huge contribution to detector's shunt resistance and can be adjusted through a temperature controller
  2. The chopping frequency also affects the highest gain setting

Backup


Shunt resistance vs. element temperature
(Typ. VR=10 mV)
10 MΩ
1 MΩ
100 kΩ
10 kΩ
1 kΩ
100 Ω
10 Ω
G12183-003K/-103K/-203K
G12183-005K/-105K/-205K
G12183-010K/-110K/-210K
G12183-020K/-120K/-220K
G12183-030K/-130K/-230K
Shunt resistance
-40
-20
0
20
40
60
80
100
Element temperature (°C)