Silicon Photodiodes - SXUV Series with Platinum Silicide Front Entrance Windows

SXUV Responsivity Stability

It is known that the UV photon exposure induced instability of common silicon photodiodes is caused by the front silicon dioxide window. The PtSi window in the SXUV series diodes replaces this SiO_2 window eliminating the XUV exposure induced instability problem.

Stability tests performed at NIST and LBL showed that quantum efficiency of these devices did not change after exposure to 10 eV 10^{16} photons/cm^2 and 100 eV 10^{22} photons/cm^2 fluences respectively. This suggests a radiation hardness of hundreds of Gigarads (Si).

Stability tests performed on the SXUV diodes with a 244 nm CW laser with 8.5 W/cm^2 power density (1.5 mm diameter spot, 150 mW beam power) show about 4.5% increase in the 244 nm responsivity after 4 days of exposure (total energy received 2.94 MJ/cm^2). As this increased responsivity did not decrease after 5 months of storage in nitrogen, it is presumed that the increased responsivity is caused by surface cleaning effects due to the high intensity laser beam.

Figure 1 shows the responsivity stability of SXUV series diodes after exposure to intense radiation at 193 nm from an ArF excimer laser with 100 Hz pulse repetition rate and an energy density of 200 mJ/cm^2 (3.9W at 100 Hz).

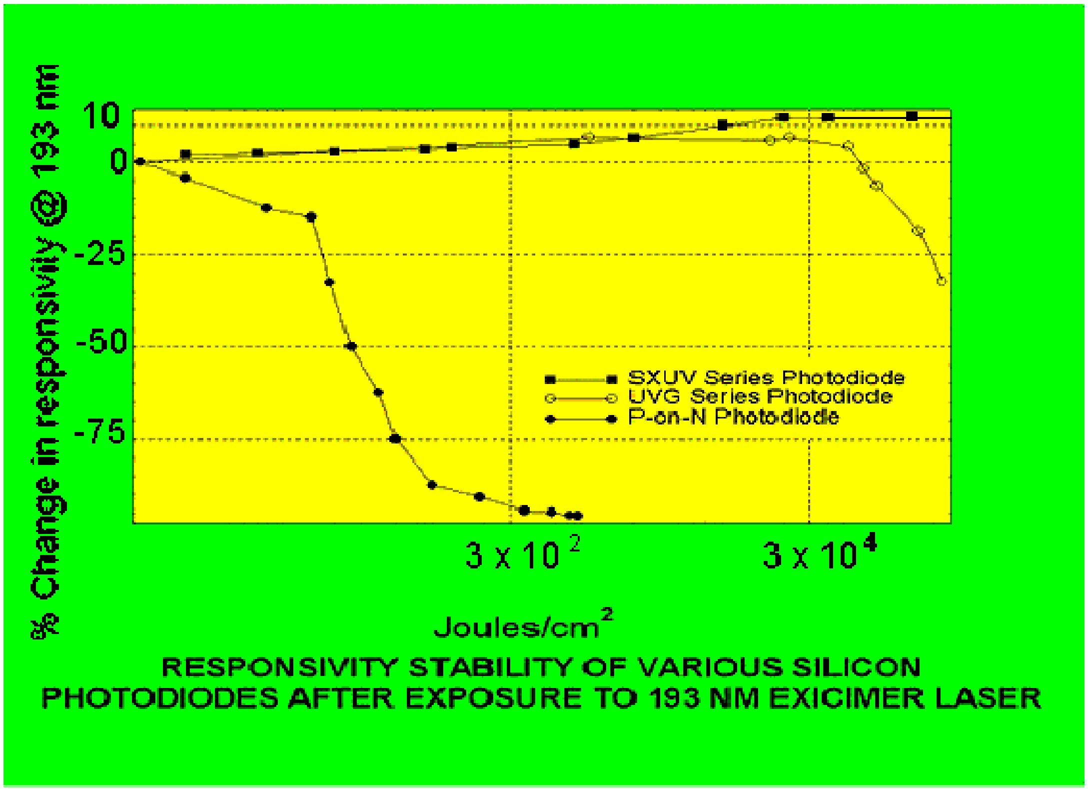

Fig. 1: Stability of SXUV diodes compared to UVG series and p-on-n diodes when exposed to 193nm radiation

Figure 2 shows responsivity stability of SXUV diodes after exposure to billion pulses of 193 and 157 nm radiation with 100uJ/cm^2 pulse energy density.

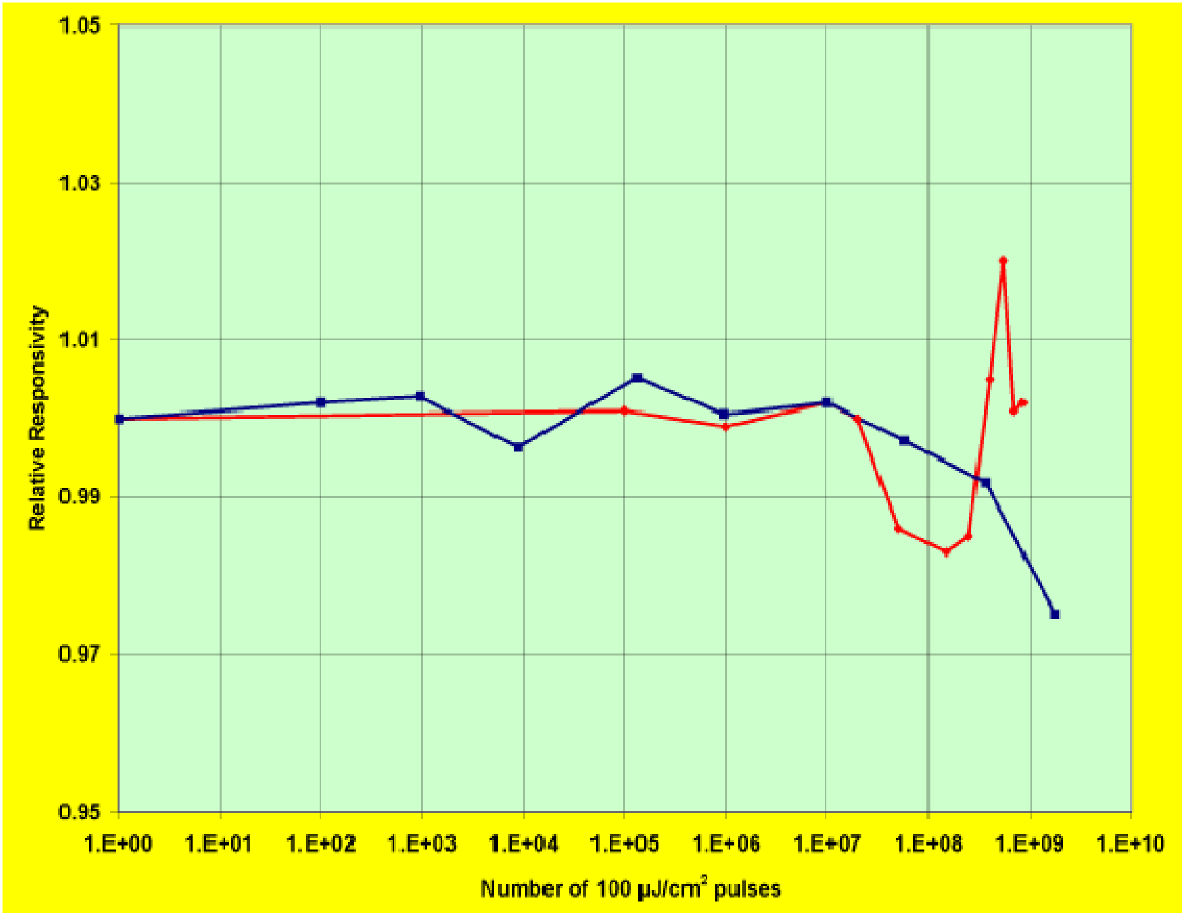

Fig. 2: Responsivity stability of SXUV series photodiodes after exposure to 193 and 157nm excimer laser:
-193nm, -157nm

Figure 3 shows the responsivity stability of the SXUV-100 diode compared to the AXUV-100G diode when exposed to 100 eV photons with $3x10^{14}$ photons/sec/cm^2 flux. After receiving a total fluence of $1.8x10^{18}$ photons, the AXUV-100G diode showed approximately 28 % decrease in response while the SXUV-100 diode showed virtually no change after the same exposure. Further exposure indicated that no change in the SXUV-100 diode responsivity is noticed after receiving a total fluence of 10^{22} photons.

Figure 3 also shows the responsivity stability of the SXUV-100 and AXUV-100G diodes when exposed to 10 eV photons with $5x10^{13}$ photons/sec/cm2 flux. Again, virtually no change in the SXUV-100 diode responsivity was noticed after several hours of this exposure.

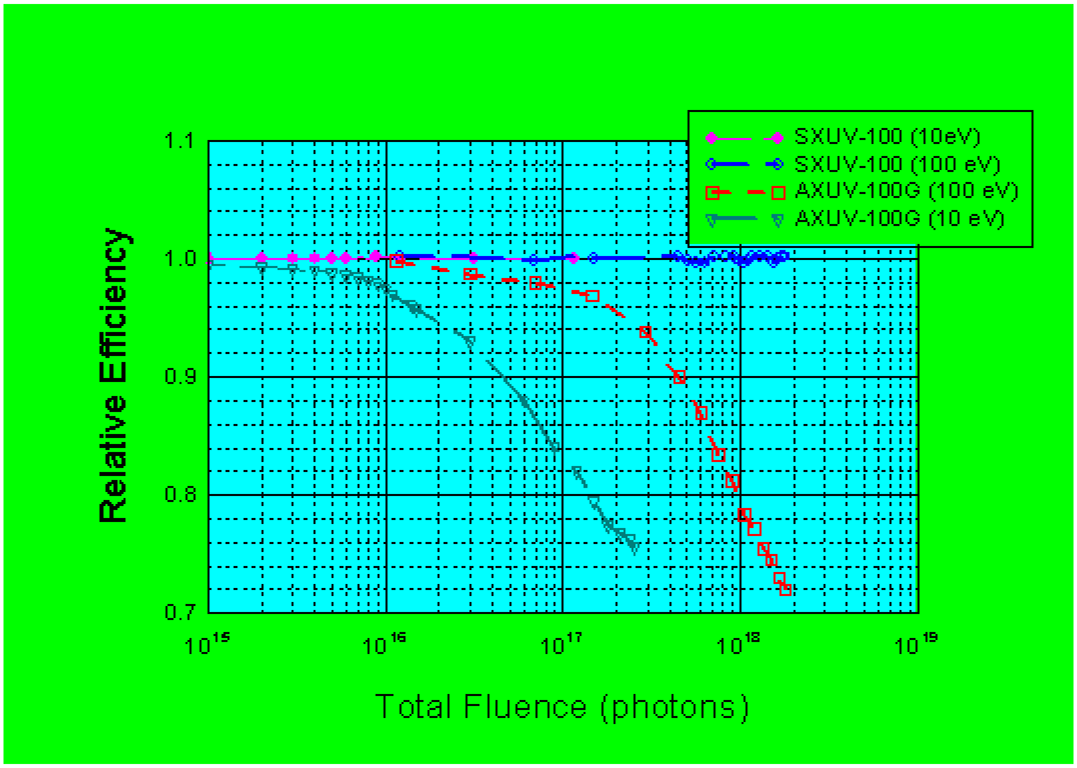

Fig. 3: Relative responsivity of SXUV and AXUV series photodiodes when exposed to
10 eV and 100 eV photons.

The SXUV-100 photodiodes are currently in the field and are being used in the feedback loop to control the energy of excimer laser pulses. They are guaranteed to have less than 3% variation in response when exposed to $1.6x10^5$ J/cm^2 total fluence of 157 nm pulses.

The SXUV photodiodes are also guaranteed to have less than 3% variation in response when exposed to $1.6x10^5$ J/cm^2 total fluence of 157 nm pulses with 100 mJ/cm^2 pulse energy density.

Figure 4 shows a scan of the SXUV-100 photodiode surface before and after exposure to 100 eV photons with a fluence in excess of 10^{22} photons/cm^2. The arrow indicates the position where the detector was exposed to the synchrotron radiation beam for several hours. The beam sized used was 0.1 mm x 0.5 mm. Taking into account the measurement uncertainty, it may be concluded that there is no change in the diode response after receiving the above fluence. Note also that uniformity of the SXUV-100 diodes is within a couple of percent when scanned with 0.1 mm x 0.5 mm beam.

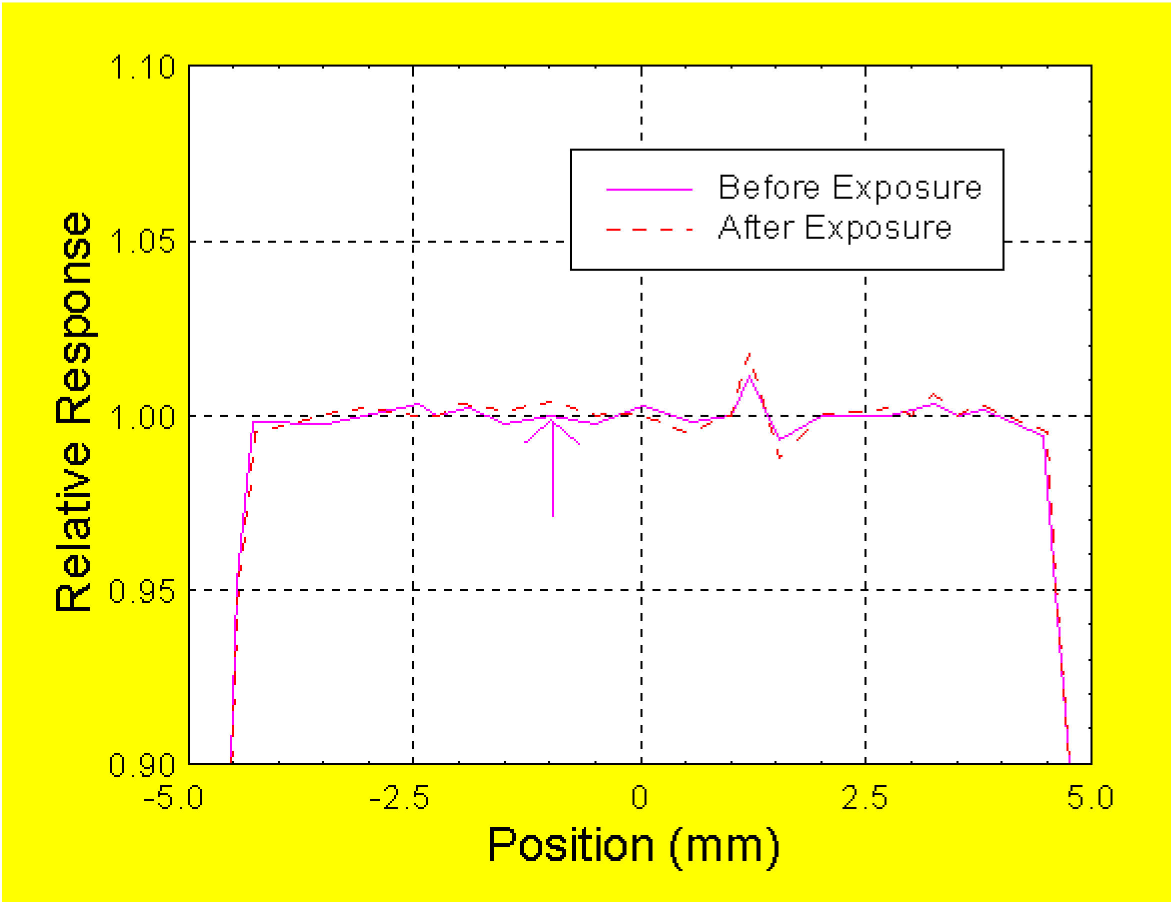

Fig. 4: Line scan of the SXUV-100 diode with 12.4 nm beam before and after exposure to 10^{22} photons/cm^2 100 eV photons

Figure 5 shows a SXUV-100 with Si/Zr filter after exposure to 16 mW of 60-110 eV photons for 13 hours. The irradiating beam spot size was 0.3mm x 0.05 mm, for a total deposited energy of 0.75 J or 5 kJ/cm^2 or approximately 4 x 10^{20} photons/cm^2. In general, addition of front metal filters does not significantly impact stability of the SXUV-100 devices. A selection of SXUV diodes with directly deposited filters is available on the SXUV filtered diode page.

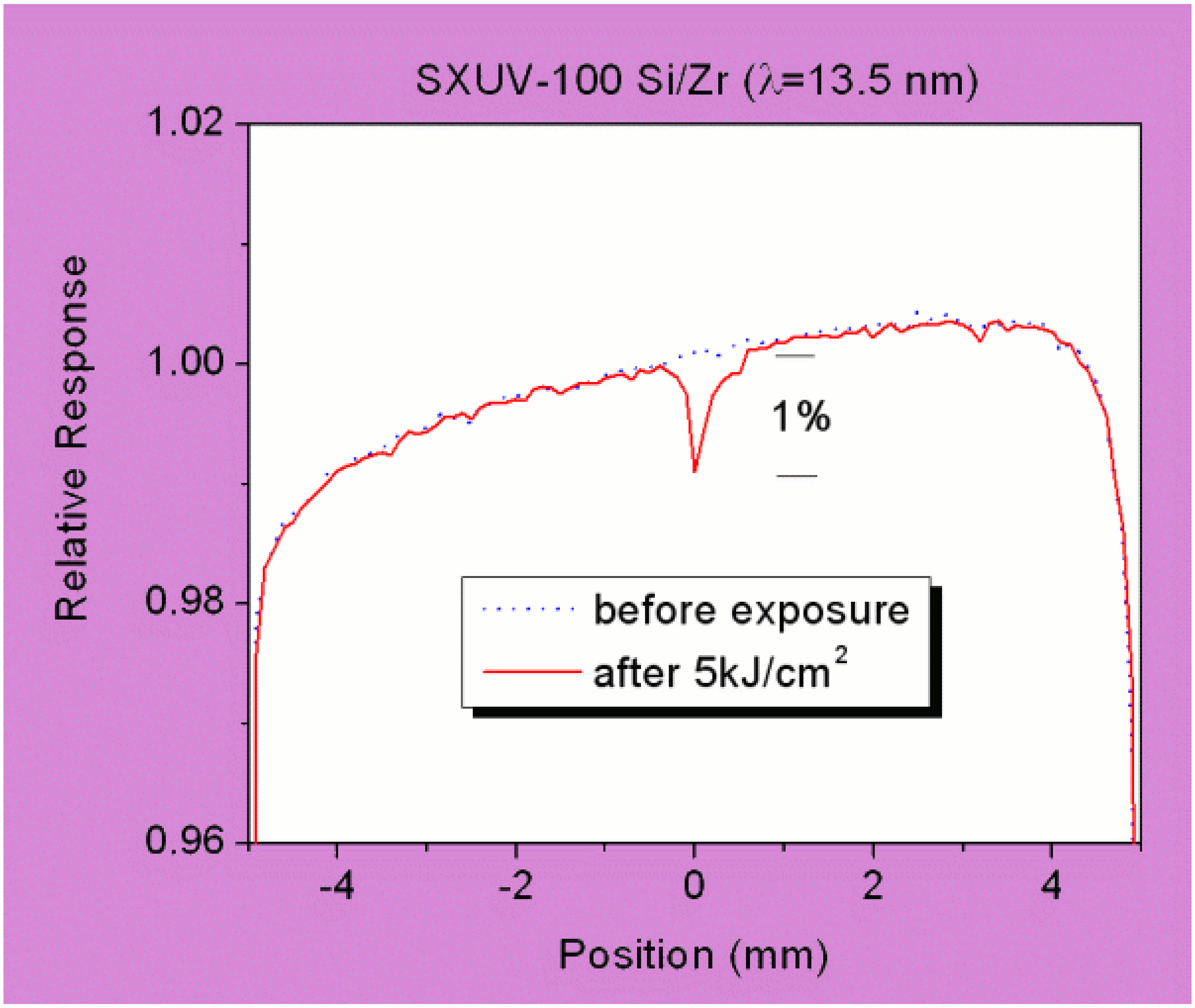

Fig. 5: Line scan of the SXUV-100 Si/Zr diode with 13.5 nm beam before and after exposure to 4 x 10^{20} 60-110 eV photons

Figure 6 shows the responsivity stability of UVG20B, SXUV20A and SXUVPS4C series diodes after irradiation by a 6.53 mW/cm^2 185 nm lamp. Total energy deposited totals 16.9 kJ/cm^2. At this exposure level, degradation was 25% over the course of one month (720 hours). SXUVPS4C and SXUV20A diodes at the same intensity did not show any significant change in responsivity over 1 month of exposure.

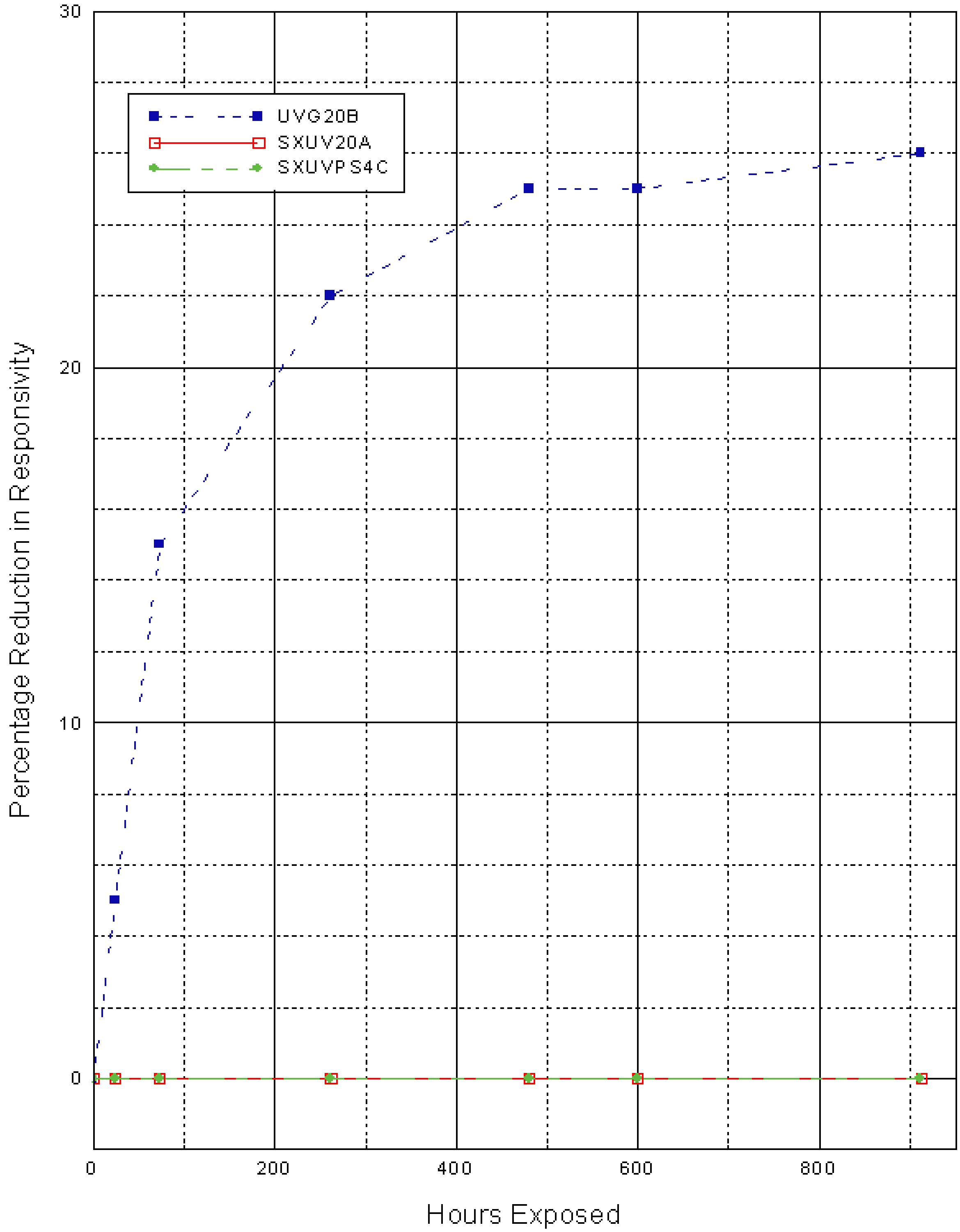

Fig. 5: Relative responsivity of SXUV and AXUV series photodiodes when exposed to 6.53 mW/cm^2 185 nm lamp irradiation.

Developed in collaboration with NIST, NIH

SXUV Pulse Responsivity

Light pulses can be very destructive to sensors and optics because of the high flux levels usually encountered. Therefore, it is necessary to have a sensor with superior radiation hardness for stable responsivity. The SXUV series photodiodes were developed specifically for sources with high flux levels such as excimer lasers and the third and fourth generation synchrotrons. Unlike pyroelectric detectors which have only five or six orders of magnitude dynamic range and a significant non-uniformity of response across the surface, SXUV series photodiodes eliminate XUV exposure induced instability problems and have over eight orders of magnitude dynamic range and better than 2% uniformity. The solid state accuracy and reliability as well as the compact size and low cost of the SXUV photodiodes will provide an effective replacement for pyroelectric detectors.

When a need arises to measure light pulse sources such as lasers, certain factors must be considered. Saturation can be apparent if the energy density of the source exceeds 1 uJ/cm^2. Applying a reverse bias to the detector can raise the threshold of saturation as well as reduce the risetime. IRD uses a capacitively coupled bias tee (part #BT-250) to accomplish this task. The BT-250 is a low noise bias insertion tee with a DC blocking capacitor that was designed specifically for use with the SXUV/UVG series photodiodes. It should be noted that there is an approximate 5% loss of signal in the bias tee that must be accounted for when making absolute measurements.

The amount of bias needed depends on the magnitude of incident flux. The bias voltage must be increased to the point that the area under the voltage-time curve ceases to increase with increased bias voltage. This indicates that the detector is being operated in the linear region, meaning all charge generated by the incident photons is collected in the external circuit. Figure 1 shows the needed bias to avoid saturation of 100 uJ/cm^2 pulses. It should be noted that the applied reverse bias should not exceed the breakdown voltage of the detector.

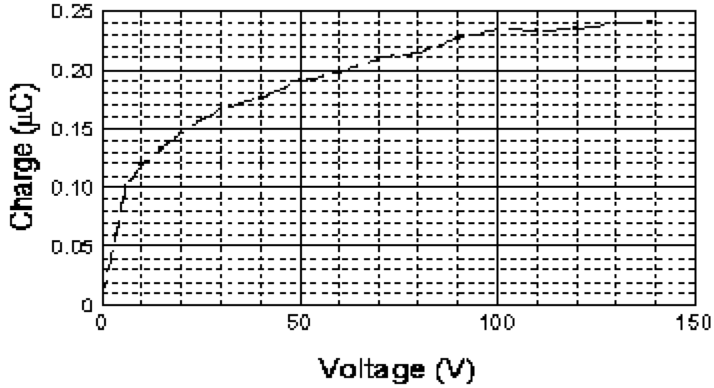

Fig. 1: Charge seen by external circuit as a function of photodiode bias for UVG-20. 193 nm

* Excimer laser pulses with 100 uJ/cm2 energy density were used for this measurement.

Pulse Energy Measurement

The energy per pulse can be calculated as follows:

The photogenerated charge Q is proportional to the area under the voltage-time curve V(t), and is explained as

$$Q = \int V(t)dt$$

$$I = V/R$$

$$Q = (1/R)\int V(t)dt$$

$$Q = A_v/R$$

where I is current, R is the input resistance of the oscilloscope, and A_v is the area of the time integrated voltage signal.

Certain digital oscilloscope can calculate the area under the voltage-time curve by integration to reasonable accuracy. Thus, the collected charge can be calculated by dividing the area under the V(t) curve by the shunting resistance. The shunting resistance is the input impedance on the scope or the feedback resistance of an operational amplifier if using one. The energy per pulse can then be calculated by knowing the quantum efficiency of the detector (# electrons generated in external circuit/ incident photon). We have

$$\text{Energy/pulse} = Q*Ep/QE$$

here QE is the quantum efficiency in (# electrons/photon) and Ep is the photon energy in eV.

Sample Measurement

An MPB 193 nm excimer laser (model # PSX-100) was used to compare the pulse responsivity of UVG-100 and SXUV-100 diodes and their measured CW responsivities. A capacitively coupled bias tee (IRD model BT-250) was used to reverse bias the detectors up to 120 V. The photodiode integrated voltage $\int V(t)dt$ was measured with a LeCroy 500 MHz digital oscilloscope with 50 ohm input impedance R and the charge Q created in the photodiode per pulse was calculated as described above.

As seen in Table 1, the correlation between the CW and pulsed 193 nm response agrees previous results for visible wavelengths [1]. This experimental verification that the CW responsivity can be used to measure pulse energy is critical to radiometric measurements of 157 nm and 13 nm pulses for which no primary standard is available presently.

		Responsivity for 193 nm Pulse Radiation					
		100 V Reverse Bias			120 V Reverse Bias		
Device	CW Responsivity @ 193 nm	100 nJ	1 µJ	2.5 µJ	100 nJ	1 µJ	2.5 µJ
UVG-100 00-26	.137 A/W	.127 C/J	.122 C/J	sat	.129 C/J	.123 C/J	sat
SXUV-100 02-2	.0104 A/W	.0101 C/J	.0108 C/J	.0105 C/J	.0102 C/J	.0108 C/J	.0105 C/J

Table 1: Comparison of CW and pulse responsivity of UVG* series and SXUV series photodiodes when exposed to100 nJ, 1µJ and 2.5 µJ pulses with a 3 mm diameter beam.

*Because of the high responsivity, the UVG diode was saturated at the 2.5 µJ/pulse energy level.

References:

1] R. Stuik and F. Bijkerk, "Linearity of P-N junction photodiodes under pulsed irradiation"

Nuclear Instruments and Methods in Physics Research A 489, 370-378 (2002).

SXUV Performance Characteristics

In addition to extreme radiation hardness, SXUV photodiodes are also resistant to environmental contaminants such as moisture. SXUV photodiodes show no change in 254 nm responsivity after exposure to 100% relative humidity for a period of four weeks.

Accelerated testing was performed on the SXUV-100 photodiodes to verify reliability. The diodes were subjected to 113 ^{0}C ambient temperature under a reverse bias of 10 V. The result was no increase in dark current after continuous operation at this high temperature for one week which is indicative of long term room temperature stability. Note that reverse bias was used in this test as SXUV photodiodes are recommended to be used with reverse bias for all excimer laser applications.

Responsivity uniformity of 1 cm x 1 cm active area SXUV photodiodes (model # SXUV-100) was found to be within ± 2% when tested at 254, 162, 120 and 10 nm. Figure 1 shows the spatial responsivity uniformity for the SXUV-100 photodiode at 121.6 nm with 1 mm diameter beam.

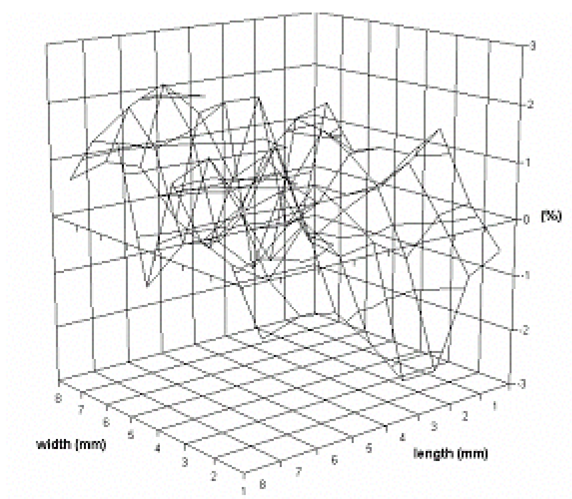

Fig. 1: Spatial responsivity uniformity of the SXUV-100 photodiode at 121.6 nm

Figure 2 shows temperature dependence of the shunt resistance. The shunt resistance was found to decrease by a factor of 2 for every 6 ^{0}C rise in temperature.

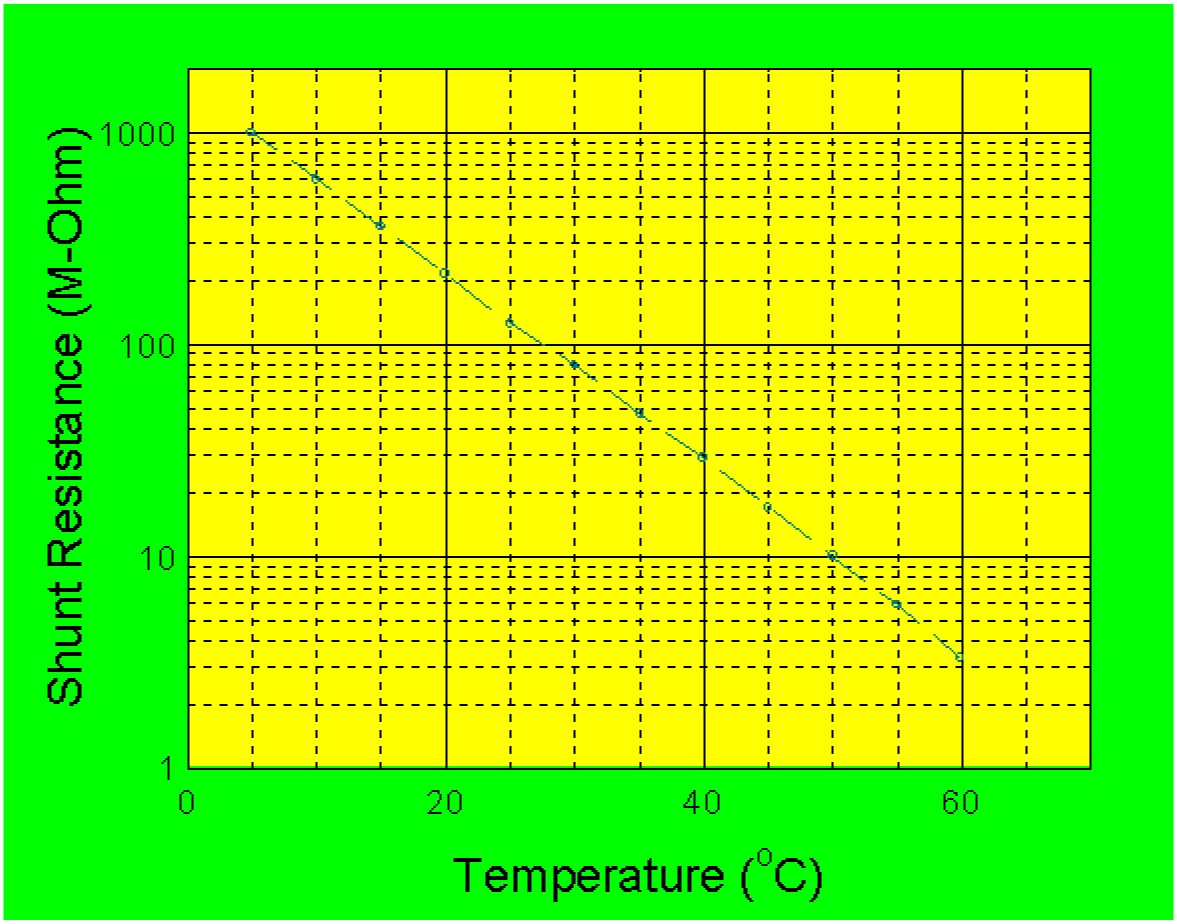

Fig. 2: Temperature dependence of Shunt Resistance of the SXUV-100 photodiode

Figure 3 shows the temperature dependence of the photodiode responsivity at 254 nm. Typically, the responsivity was found to decrease by 0.1% per degree Celsius. Because the SXUV photodiodes have high surface recombination (indicated by their low responsivity), the decrease in responsivity at higher temperatures is presumably caused by an increase in the surface recombination velocity.

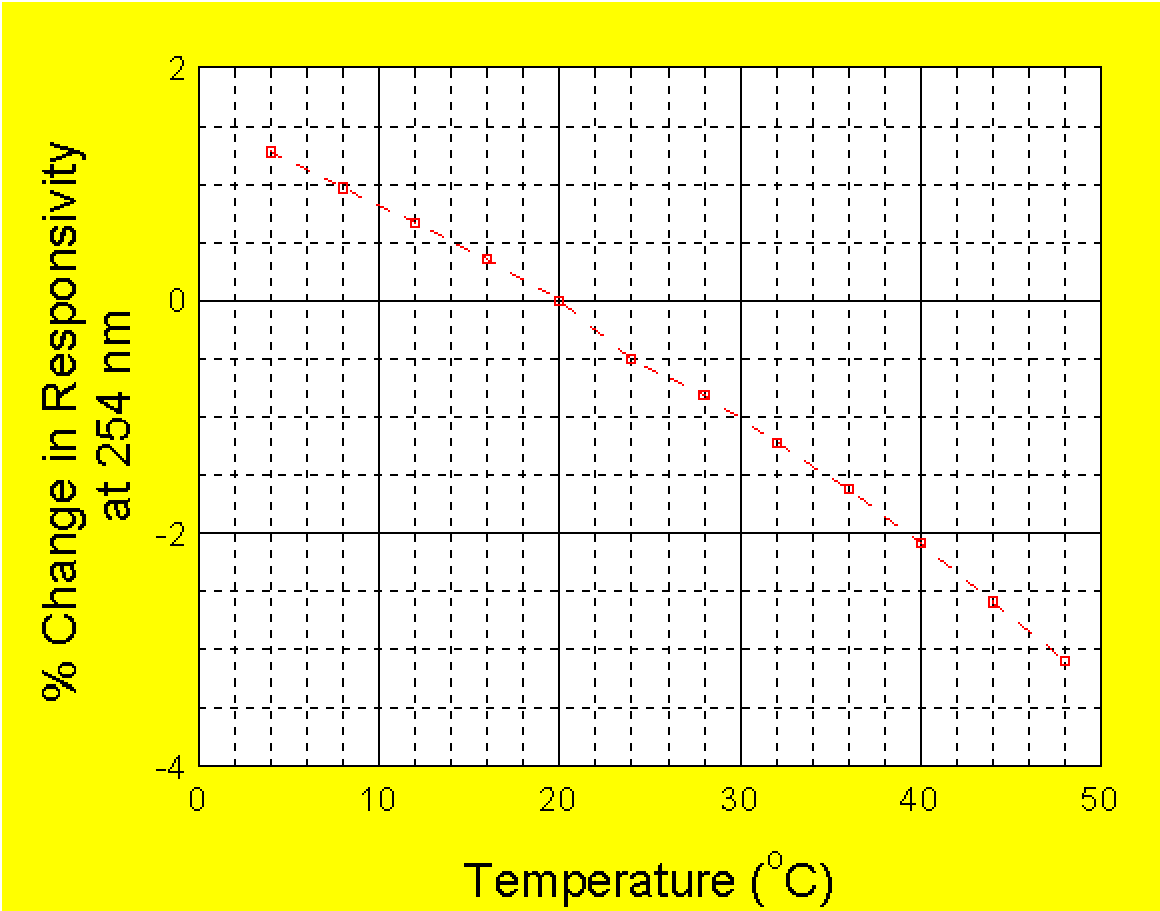

Fig. 3: Change in 254 nm responsivity of SXUV series diodes with temperature

SXUV-100 photodiodes are currently in the field. Some SXUV photodiodes have seen use in feedback loops to control the energy of excimer laser pulses.
