Technical Note 103

Response Enhancement for the Loral CCDs

using Ultra-Violet Flooding.

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1. Introduction.

The Loral CCDs in their raw state, as delivered from Mike Lesser, have a spectral response similar to that of a thick, front-sided detector, i.e. around 50% response at the peak (600nm) and no response at wavelengths shorter than about 400nm. This can be compared with say the SITe CCDs which have a peak response of about 70% at 600nm and an Ultra-Violet response of about 30% (350nm). Although the Loral devices have been thinned and should therefore exhibit some response in the blue (<400nm) this can only be achieved by a process of illuminating the surface with Ultra-violet light for some minutes in dry air (or Oxygen). This lack of Ultra-Violet response is due to the manufacturing process these devices are subject to.

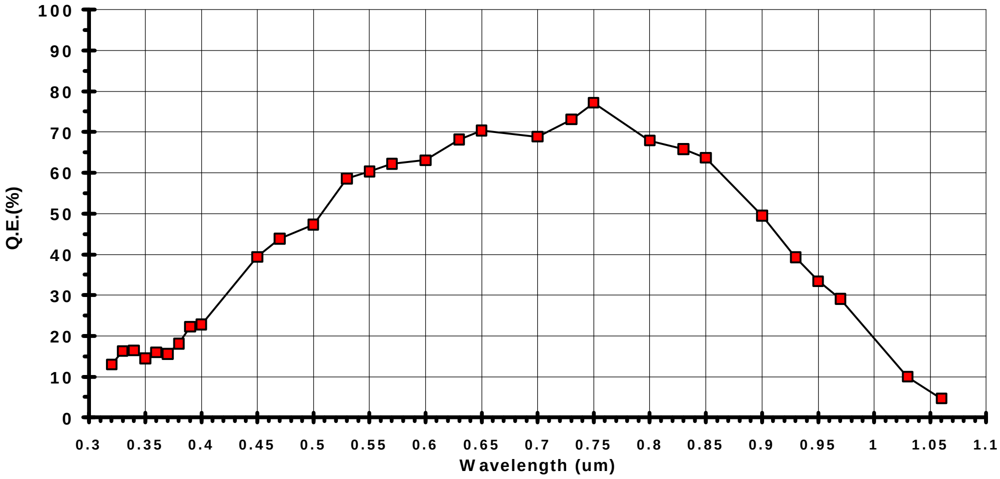
This process, to achieve a thinned response, results in the back-side surface being damaged (in fact by the acids used for the etching process). This damage manifests itself in a potential barrier close to the back-side surface where the UV photons are converted into electrons. Unfortunately because of the presence of this barrier, the electrons are inhibited from moving to the charge collection sites underneath the electrodes at the front-side surface, a distance of 10um or so. To over-come this problem the back-side surface can be treated in a variety of ways and in fact the SITe and EEV CCDs are treated in a manner which results in a permanent fix to this problem. The ultra-violet and peak response of these devices is however rather less spectacular than that obtained by the UV flooding technique. The Loral CCDs have to have their surface potential modified by introducing Oxygen atoms into the surface via the use of Ultra-Violet light. This process has to be carried out at room temperature in the presence of dry air. Once the response had been modified by this process and the CCD cooled to operating temperature, the response should remain stable for weeks to months.

2. Flooding Process.

The Loral response (for device **W7-4)** as measured at RGO is given in the accompanying figures for varying conditions; before flooding at room temperature, after flooding at room temperature and at operating temperature. All the measurements were taken in photo-diode mode i.e. with the detector acting like a simple diode and measuring the current flowing due to the generation of photo-electrons at all the wavelengths.

The first curve shows the situation before the UV flood at room temperature. Note the small response in the UV due to a prior flood some weeks before this date.

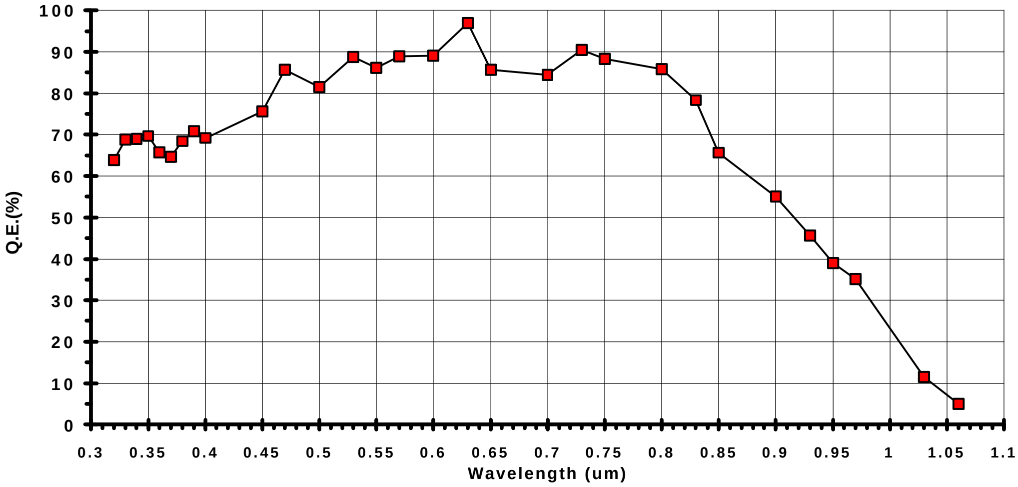
Spectral Response of Loral W7-4 Science Array.
T= RT. Before Cd UV Flood. APO, RGO. 10/05/96.



The next figure shows a typical response curve (at room temperature) after the device has been UV flooded.

Spectral Response of Loral W7-4 Science Array.

APO, RGO. 12/05/96.



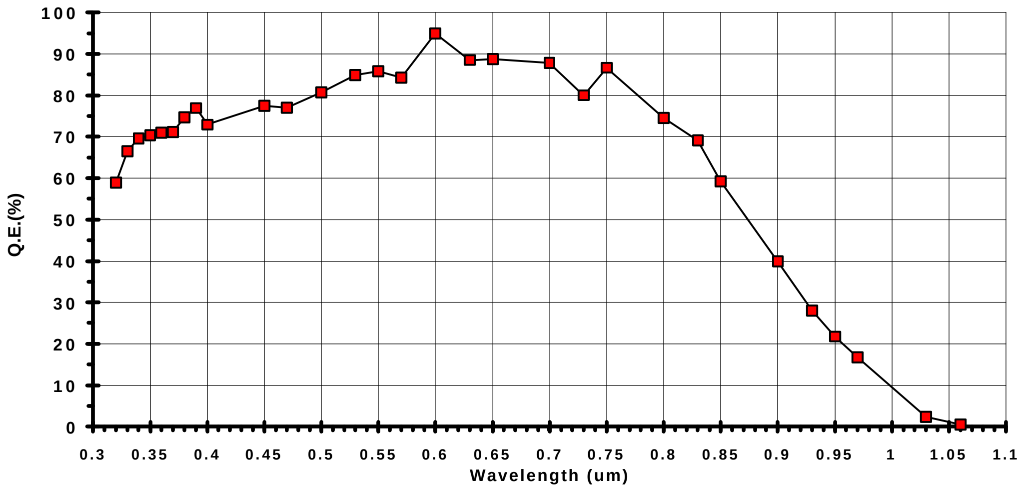
The points to note are-

- the UV (350nm) response is 70%,

- the peak response (600nm) is 90%
- the red response (900nm) is 55%

This curve was obtained at room temperature but does not change when the chip is cold, see following data

Spectral Response of Loral W7-4 Science Array.
T= -100. After Hg/Cd UV Flood. Std Baking. Average of 3 runs.
APO, RGO. 14/03/96.



The Loral UV response is 70% between 320nm and 400nm (as measured at RGO). If it is suspected that this response is not being achieved, then, in the first instance, it is recommended that the chip be **re-tested on the portable Jelley Rig** to confirm this. If the UV response has indeed started to deteriorate then re-flooding the device should be undertaken. If for some reason water vapour contamination of the chip surface is suspected, then a more rigorous process is required involving ***baking*** the CCD and/or cryostat at around 90°C - see Technical Note #104 for more details.

The UV flooding process for the chip requires the presence of dry air (or dry Oxygen - this has been found to produce no significant improvement in respose and so dry air should be used in preference); the chip will therefore have to be brought up to room temperature for this operation to take place. The cryostat should be emptied of Liquid Nitrogen the day before flooding is to be undertaken to allow the chip and inside of the cryostat to reach room temperature in a controlled fashion. The cryostat temperature **should not** be raised in an artificial manner as this *may* introduce water vapour onto the surface of the chip if this becomes cooler than the rest of the inside of the cryostat. Ensure that the chip is at ambient temperature before releasing the vacuum and opening the cryostat.

Once the chip is at room temperature the next operation will be UV flooding of the chip surface. The UV lamp should be turned on 10 minutes prior to flooding to ensure adequate, even illumination during the flooding process. The output of the lamp after 10mins has been measured at RGO and found to be flat and even over the major part of its illumination area. Care must be taken to avoid the lamp output as the UV can be harmful to skin and eyes - wear goggles and gloves if you are working in close proximity to the lamp for some reason.

Once the chip has reached room temperature the cryostat must be mounted on the Turbo pump **but the cryostat valve left closed so that it remains under vacuum.** The line should be pumped down to a vacuum of, say, 10^{-4} mbar and then the cryostat valve opened to the line and the pump turned off. This will permit dry air to enter the cryostat through the sorb on the back of the pump. Once the cryostat is at ambient pressure the valve on the cryostat should be closed, this prevents any water vapour or other contamination of the inside of the cryostat.

The CCD will need to be placed about 5cms in front of the UV lamp, the centre-line of the chip matching that of the lamp. The even illumination output of the lamp will result in an even flooding response of the chip at this distance. It is not too critical (to +/-1cm). The chip should be exposed for about 30minutes, Mike Lesser reports that any time beyond 10mins does not result in any improvement of UV response. Once the flooding is complete the cryostat should be placed on the pump and evacuated to a few x 10^{-5}. Once this vacuum is attained the cryostat should be cooled immediately. No more than a few hours should elapse between flooding and cooling otherwise the UV enhancement may start to deteriorate. Once the chip is cold, at the **ING**, the response may be measured as detailed in the next section.

To conclude this section, there follows a simple recipe for flooding the Loral CCDs-

- Allow the chip to naturally warm up to room temperature,
- When at ambient temperature, connect the cryostat to the turbo pump and evacuate the hose to the crysostat,
- When the line is at good vacuum, 10^{-4} mbar, open the cryostat valve to the pump,
- wait a few minutes to pump the whole system down a liitle further,
- Switch on the UV lamp in preparation for flooding,
- Switch off the pump. This will purge the cryostat through the pump, with dry air,
- Dry air is required for the flooding process,
- Close the cryostat valve,
- After the UV lamp has been on for 10 minutes, present the cryostat to the lamp for flooding, the distance from the cryostat window to the flooding lamp needs to be about 3.5cms, about 5cms from the chip,
- Allow the chip to be flooded for 30 minutes,
- Switch off the lamp, connect the cryostat to the pump and pump down the head,

When a vacuum of around a few x 10^{-5} or better is attained, close off the cryostat valve, disconnect and immediately cool to operating temperature.

3. ING Response Measurement.

If possible, a good indication of any fall in response can be obtained by measuring the direct current flowing between **RD** (Reset Drain) and **SS** (Substrate) using a pico-ammeter and a suitable connector to the chip. Filtered light at a wavelength of 400nm can easily indicate if there is a problem. For instance at RGO with this set-up, we have measured the room temperature response at 400 nm to be around 20nA. When the chip is operating correctly, this current is seen to *increase* slightly when the temperature drops to operating (-110°C). In any instance this current should not decrease. For instance, when the worse contamination occurred with another device at RGO, the Room Temperature response at 400 nm was about 20nA. However, lowering the temperature produced a linear decrease in response down to around 8-9nA at operating temperature. This reflecting a loss in QE of about 50%. Warming the chip back to room temperature restored the Q.E. to about the level seen at the start.

At the ING, the spectral response measurement can only be undertaken using the Portable Jelley Box which was (18/5/96) calibrated against Tek5/Tek3. The image mode measurement means that the CCD will have to be cold to obtain the response data. Below is data obtained for Tek5 for the wavelength range 400-1000nm and with Tek3 for the 350nm measurement (the change in head was due to Tek5 head being required on the telescope) from which the response of the Loral CCD can be obtained.

(NOTE: At the time quoted above, the 400-1000nm fluxes appeared to require a correction to the ORIGINAL RGO flux calibration, of about x1.7 and the 350nm flux about x0.16 to obtain the Q.E. of the Loral. This correction was required due to a change in the position of the internal OPAL with respect to the calibration made at the RGO, this resulted in the signal at the output port being higher by the factors quoted above.)

The data for Tek5/Tek3 is shown in the table below along with the known spectral response of these devices as measured at RGO. This enables the flux at the output port to be established and hence used to determine the response of Loral CCD.

Quick-speed, T=-100°C
Pixel size = 0.024mm x 0.024mm
Gain of CCD = 1.2 e/adu for Tek5 (400-1000nm)
Gain of CCD = 1.83 e/adu for Tek3 (350nm)*
Lamp current of illumination source = 3.15 A
600x600 window used at 0,0

F#	Wave (nm)	time (s)	Bkgnd. (adu)	Signal (adu)	Net (adu)	RGO Q.E. (%)	Derived ING (RGO) Flux (ph/s/mm^2)
1	350	200	2889	2914	25	30*	1324(8478)
2	400	100	459	3256	2797	55	136375(80390)
3	500	30	448	7968	7520	67	1003290(595036)
4	600	30	453	22161	21708	72	2643670(1558800)
5	700	20	455	21539	21084	73	3959402(2334400)
6	800	20	465	27113	26648	62	6005310(3540420)
7	900	20	478	24984	24506	35	9496665(5593550)
8	1000	20	459	6298	5839	10	8258571(4867360)

The Flux at each wavelength can be determined from the relation-

$$F = \left(\frac{S}{d^2}\right) x \left(\frac{G}{t}\right) x \left(\frac{1}{QE}\right)$$

where F = the Flux (in photons/sec/mm^2) at the given wavelength,
S = the measured net signal (adu)
d = the pixel size in mm,
G = the measured Gain (e/adu),
t = integration time in seconds,
QE = known QE from measurements at RGO.

For the Tek3 CCD at 350nm this came out as

$$F = \left(\frac{25}{0.024^2}\right) x \left(\frac{1.83}{200}\right) x \left(\frac{1}{0.3}\right) = 1324\, ph\ s^{-1} mm^{-2}$$

The Loral was measured in the same way using the flux values from the table above.

Gain=1.2 e/adu, quick speed, T=-110, EEV9 CCD controller
Pixel size = 0.015mm x 0.015mm
Lamp current of illumination source=3.15A
600x600 window used at 0,0 for LORAL1

F#	Wave (nm)	time (s)	Bkgnd. (adu)	Signal (adu)	Net (adu)	ING Tek Flux (ph/s/mm^2)	Loral Q.E. (%)
1	350	200	1502	1537	35	1324	71
2	400	100	1097	2540	1443	136375	74
3	500	30	1092	4744	3652	1003290	83

4	600	30	1109	12205	11096	2643670	97
5	700	20	1110	11613	10503	3959402	93
6	800	20	1118	14056	12938	6005310	75
7	900	20	1114	12289	11175	9496665	41
8	1000	20	1101	3056	1955	8258571	8

The simplified relation for the QE of the Loral (or any other chip) is-

$$Q.E_L = \frac{S_L}{S_T} x \frac{G_L}{G_T} x \frac{d_T{}^2}{d_L{}^2} xQ.E_T$$

where

QE_L = QE of the Loral
S_L = Net signal from Loral (adu)
S_T = Net Signal from Tek (adu)
G_L = Gain of Loral (e/adu)
G_T = Gain of Tek (e/adu)
d_T^2 = pixel area of Tek in mm^2
d_L^2 = pixel area of Loral in mm^2
QE_T = Known QE of Tek (RGO measurement)

So that

$$Q.E_L = 1.7x\left(\frac{S_L}{S_T}\right)xQ.E_T$$

For the Tek#3 with a gain of 1.83 (e/adu) and Loral #1 with a gain of 1.2 (e/adu)

At the RGO these measurements will be made in either Diode Mode (see Technical Note #105) or in Imaging mode on the Jelley box.

4. Concluding Remarks

The Loral #1 Cryostat and the CCD have both been baked well to remove any water vapour contamination.. Unless there has been a SERIOUS ingress of water vapour, the cryostat does not have to be re-baked. This makes matters much easier as the chip itself can be processed, i.e. baked WITH SOME CARE, on its own. This, in both previous cases, was found to be the root cause of changes in response with temperature. Baking the cryostat alone, with no chip installed, did NOT solve this problem. If however the cryostat has become contaminated then this will have to be baked in addition to the chip - see Technical Note #104 for details.