Dark Current Measurements on a State of the Art Near-IR HgCdTe 1024x1024 Array

Scott D. Johnson[a]*, Elizabeth Polidan*[a]*, Augustyn Waczynski* [a]*, Robert J. Hill*[b]*, Gregory S. Delo*[a]*, Massimo Robberto*[cd]*,*
Carey M. Lisse[c]*, and Laura Cawley*[c]

[a]*Global Science & Technology, NASA/GSFC, Mail Code 685, Greenbelt MD, USA;*
[b]*Raytheon ITSS, NASA/GSFC, Mail Code 685, Greenbelt MD, USA;*
[c] *Space Telescope Science Institute, 3700 San Martin Dr., Baltimore MD, USA;*
[d]*On assignment from the Astrophysics Division of the Space Sciences Directorate of ESA*

Abstract

The NASA/GSFC Detector Characterization Laboratory (DCL) has acquired, for the HST Wide Field Camera 3 project, a preliminary engineering HgCdTe, 1024x1024, 18.5 m m pitch array manufactured by Rockwell Science Center. The device is designed for the near infrared with a cut-off at approximately 1.73 m m and a dark current at 150K of 0.2 e^-/sec/pixel. We have made measurements at the DCL to confirm that this preliminary device meets the design specifications. In order to achieve the most reliable results for the dark current, three techniques were used that mitigated non-linear drift problems. We discuss the viability of these methods for determining dark current and the results of the measurements on the device.

Introduction

The Wide Field Camera 3 (WFC3) is a new panchromatic imaging instrument being built for deployment aboard the Hubble Space Telescope (HST). The instrument is designed to have two independent imaging channels, one in the near-UV/visible wavelength range and the other in the near-IR wavelength range. The near-UV/visible channel will cover from approximately 0.2 to 1.0 mm, while the near-IR channel will span the wavelength range 0.85 to 1.7 mm. This near-IR channel will provide a capability to study a wide range of astrophysical objects, including circumstellar dust, brown dwarfs, and distant galaxies. These observations will also uncover objects of interest to future users of the Next Generation Space Telescope.

The IR channel uses a Mercury Cadmium Telluride (HgCdTe) detector array manufactured by the Rockwell Science Center (RSC) that is engineered for a long cutoff wavelength of 1.7 mm. This is different from typical HgCdTe devices, which have a cutoff wavelength of approximately 2.5 mm. The choice of this cutoff wavelength is driven by the desire to be limited by the background contribution from the sky (zodiacal light) and the thermal emission of the telescope optics, given the anticipated detector operating temperature of 150 K. The basic design goals of the detector are listed in Table 1.

Table 1.

In support of the WFC3 project the GSFC

	IR	
Format	1024 x 1024	pixels
Pixel Size	18.5	µm
Spectral Range	0.85 to 1.7	µm
Dark Current	< 0.2	e^-/sec/pix
Readout Noise	< 15	e^-/pix/ readout
Operating Temp	150	°K

Detector Characterization Laboratory (DCL) is investigating IR arrays and CCDs. The DCL's goals are to characterize these devices to determine if they will meet the science requirements for the WFC3 project. To this end, the DCL has acquired a preliminary engineering array manufactured by RSC. The 1024 x 1024, 18.5 mm pitch HgCdTe array is grown by molecular beam epitaxy on a CdZnTe substrate device and is hybridized to a silicon multiplexer with Indium bumps. The device is designed to have a cutoff at approximately 1.7 mm in order to meet a dark current goal of 0.2 e^-/sec/pixel at 150 K.

Due to non-linear drift problems that are not well understood the dark current data are problematic. In order to achieve the most reliable results for the dark current, three techniques are used to ensure that the device meets the dark current requirements. Though the results vary within the three methods used, they all indicate that a dark current of 0.2 e^- /sec/pixel at 150 K is achievable. In this poster, we discuss the viability of these methods for determining dark current.

Dark Current Methods

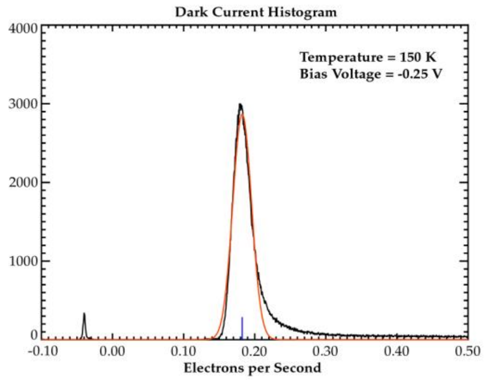
In our initial examination of the dark current data's power spectrum density, we observed anomalous noise sources in many of the data files. Specifically there is a drift that is apparently non-linear in these files. The cause of this drift is unknown. Its existence has prompted us to try a variety of methods to calculate the dark current while minimizing this effect.

The classic formula for dark current is

$$i_{dark} = \frac{\left(\langle signal\rangle - \langle reset\rangle\right) gain}{t_{exposure}}$$

The expression is correct under the assumption of a purely Gaussian distribution of the histogram of pixel intensities.

Since the dark current in the device reported here does not follow a Gaussian distribution (see Figure 1), the "mean" dark current may not be the best value to report. An alternative (potentially better) way to report the dark current in cases like these would be to define a certain number of pixels (say 90%) that must have a dark current equal to or below the reported dark current. In this poster though, we do report the "mean" dark current as if the distribution was Gaussian. We are presently testing other methods to report dark current for these devices that is more representative of the dark current in actual use.



The dark current is investigated at a range of temperatures and detector bias voltages.

Figure 1

Each measurement sequence consists of a series of exposures at the same temperature, bias voltage, and exposure time. Within a single exposure a number of frames are taken before and after exposure. The pre-exposure frames (images) are referred to as "reset frames" and the post-exposure frames as "signal frames", and the difference between them as "dark frames". A second set of reset frames is taken after the signal frames.

The first method (modified standard method) of estimating the dark current uses the second set of reset frames to correct for the drift that occurs during the exposure. We then follow the classical formula above to calculate a dark current. Since the reset frame was taken immediately after the signal frame, it provides a better estimate of the true bias level at the time the dark data was read out.

The second method (variance method) exploits the fact that the dark current follows Poisson statistics. Starting with two dark files that have the same exposure time, temperature, and detector bias, we subtract the corresponding reset frames from each of the signal frames, and then subtract the resulting images from each other. The variance in the final subtracted image contains contributions from both the dark current and read noise. The read noise is calculated using two reset frames that are taken consecutively in time. The total variance and read noise variance are used to determine the dark current according to the following formula.

$$i_{dark} = \frac{\frac{1}{2}\left(\sigma^2_{total} - 4\sigma^2_{read}\right) gain^2}{t_{exposure}}$$

where σ^2_{total} is the variance of the subtracted dark images.

This method is insensitive to drifts (though it could be affected by other sources of noise).

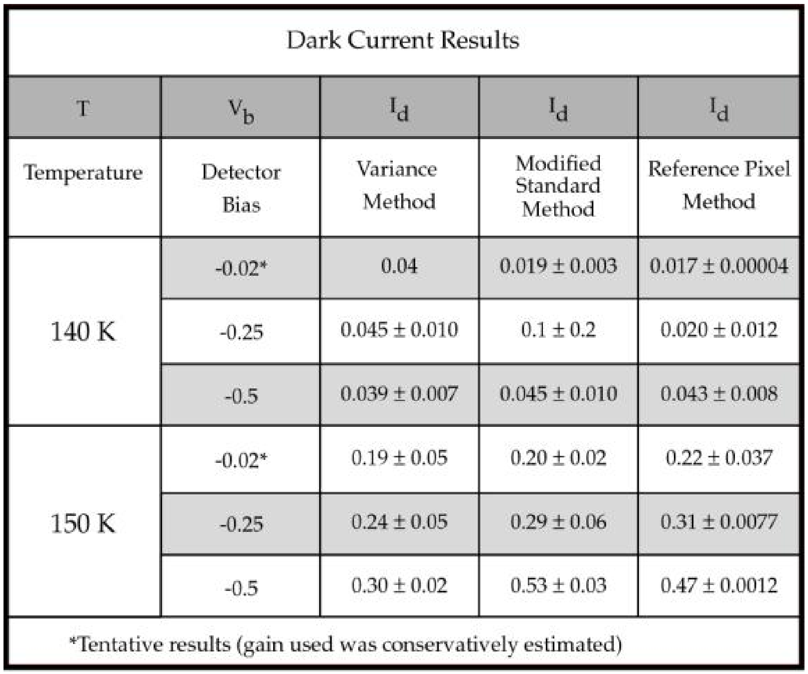
The third method (reference pixel method) uses pixels in the array, which do not respond to light, as reference pixels. These "inactive" pixels provide an estimate of the bias level for the image. The dark current is given by

$$i_{dark} = \frac{\left(\langle dark image\rangle - \langle inactive\ pixel\ image\rangle\right) gain}{t_{exposure}}$$

The first and third method can still be affected by drift if the drift is not well behaved. The second method should not be affected by drift but could be affected by other noise to a greater extent. Results for the different methods are shown in Table 2.

Table 2

The Long Wavelength QE Cutoff



Dark Current Results

T	V_b	I_d	I_d	I_d
Temperature	Detector Bias	Variance Method	Modified Standard Method	Reference Pixel Method
140 K	-0.02*	0.04	0.019 ± 0.003	0.017 ± 0.00004
	-0.25	0.045 ± 0.010	0.1 ± 0.2	0.020 ± 0.012
	-0.5	0.039 ± 0.007	0.045 ± 0.010	0.043 ± 0.008
150 K	-0.02*	0.19 ± 0.05	0.20 ± 0.02	0.22 ± 0.037
	-0.25	0.24 ± 0.05	0.29 ± 0.06	0.31 ± 0.0077
	-0.5	0.30 ± 0.02	0.53 ± 0.03	0.47 ± 0.0012

*Tentative results (gain used was conservatively estimated)

In addition to dark current, the DCL measured the relative quantum efficiency (QE) to confirm a cutoff of 1.7 mm. To measure the QE the DCL compared the response of the device to the response of a calibrated diode. The measurements were taken over a range of wavelengths (where the device is expected to operate) with a bandwidth of 0.003 mm. The cutoff wavelength is defined as the wavelength where the QE is 50% of the peak QE. In Figure 2 a derived relative QE curve shows a cutoff of 1.73 mm. Furthermore the cutoff is very sharp, going from peak to almost zero QE within a 0.1 mm range.

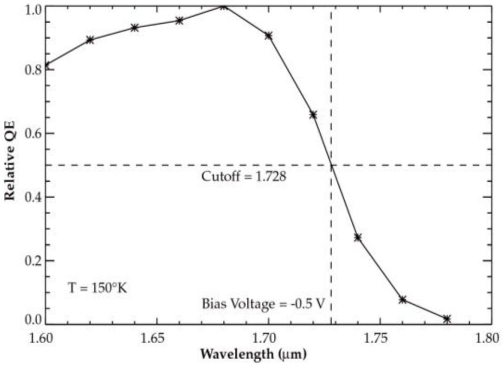


Figure 2

The methods used here for calculating dark current have a number of advantages and disadvantages depending on the data. Both the modified standard method and the reference pixel method are susceptible to non-linear drift, but are less affected by other sources of noise. The variance method is less susceptible to non-linear drift, but is much more susceptible to other sources of noise in the data. With data that has non-linear drift and noise, it is necessary to use multiple methods to get a good indication of the dark current.

For the preliminary engineering device, the DCL has confirmed that a sharp cutoff in QE occurs at 1.73 mm, as designed. The DCL has also confirmed that the HgCdTe technology is capable of delivering a dark current of 0.2 e^-/sec/pixel at 150 K. This provides confidence that the WFC3 near-IR detector will meet project specifications.