TEST RESULTS WITH 2Kx2K MCT ARRAYS
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In 1997 the University of Hawaii, Subaru, and ESO jointly contributed to fund the Hawaii2 2048x2048 project. The performance of a first LPE 2Kx2K engineering grade and an LPE 2Kx2K science grade array, delivered within the framework of this contract, has been evaluated. Both arrays have a cut-off wavelength of \( \lambda_c = 2.6 \) mm.

At a temperature of 60 K, the dark current of the science grade array is 0.004 e/s. Assuming a g-r surface current mechanism the temperature dependence of the dark current is proportional to \( \exp(-E_g/2K_bT) \). For the science grade array the measured dark current yields the correct effective temperature \( T_{eff} = E_g/2K_b \), but for the engineering grade array \( T_{eff} \) is only one third of its nominal value. The peak quantum efficiency of the science grade array is 84.4%. The readout noise is 14 electrons rms for a single double correlated clamp and 5 electrons rms for readout with 16 Fowler pairs. The LPE 2Kx2K Hawaii2 science grade array is foreseen to be installed in the MAD camera to test a multiconjugate adaptive optics system.

Five Hawaii2 2Kx2K double layer planar heterostructure MBE arrays grown on CdZnTe substrate are in production: four arrays for the multiobject spectrograph NIRMOS (\( \lambda_c = 1.9 \) mm) and one array for the integral field spectrograph SINFONI (\( \lambda_c = 2.5 \) mm). All five detectors will be hybridized to the Hawaii2-RG multiplexer.

Introduction

With the availability of large format IR arrays it was possible to extend the multi-object spectrograph concept to the infrared. Hence, the VIRMOS project was started in 1997 to build both an optical and an infrared multi-object spectrograph for the VLT with capabilities of direct imaging, multi-object spectroscopy and integral field spectroscopy. In order to minimize development costs the infrared instrument NIRMOS is designed to be similar to the optical instrument VIMOS which is now in the commissioning phase at the VLT on Paranal.

NIRMOS consists of 4 independent imaging spectrographs having a resolution of R~2500 covering a field of 4x6x8 arcmin2. The four detector cryostats will be equipped with 2Kx2K Hawaii-2RG MBE arrays having a cut-off wavelength of \( \lambda_c = 1.9 \) mm to cover the J and H bands. The detectors do not need to be buttable. The continuous flow detector cryostats cool the detectors to a minimum temperature of 86 K and have cryogenic filter wheels including linear variable filters to reduce the thermal background for H-band spectroscopy. The grism spectrographs are contained in an optical box which may be cooled to reduce the thermal flux in H-band. The mask focal plane is at room temperature.
Measurement Setup

A NIRMOS prototype continuous flow test cryostat was built to start the evaluation of the Hawaii2 arrays. The minimum temperature of 86 K, which can be achieved with the continuous flow system, is adequate for detectors having a cutoff wavelength of \( \lambda_c = 1.9 \) mm but too high for the first two Hawaii2 arrays having a cut-off wavelength of \( \lambda_c = 2.6 \) mm. For this reason the test camera was upgraded with a pulse tube two stage closed cycle cooler. The moving displacer of a standard Gifford Mac Mahon closed cycle cooler is replaced by an oscillating pressure wave in a pulse tube. This has the advantage that the pulse tube has no moving cryogenic parts and is completely free of vibrations. Unfortunately, the cooling power of a pulse tube is strongly dependent on orientation. In our setup, with the pulse tube in horizontal position the detector reaches a minimum temperature of 96 K and with the pulse tube in vertical position the minimum temperature is 41 K. The cold finger of the pulse tube is at 21K.

The arrays are read out by accessing the internal bus directly. All 32 analog outputs are used and fed into a symmetrical operational amplifier located near the focal plane on the fan-out board which is at cryogenic temperatures. The readout multiplexer has an on-chip output source follower for each of the 32 video channels to which the internal video signal bus is connected. The user has also direct access to the internal signal bus. The bus can be connected to +5 volt by an external 200KW load resistor. The internal bus is directly connected to the input of an external operational amplifier, located as close as possible to the detector signal pins for maximum immunity to noise pickup. A linear CMOS operational amplifier was selected (Texas Instruments LinCMOS TLC2274) which contributes ~ 3 electrons rms to the readout noise of a double correlated clamp. The design of differential data line drivers using these cryogenic CMOS amplifiers is shown in the schematics above and has been described in an SPIE paper. In this configuration the on-chip output source followers are not used. Hence, their glow is eliminated when multiple sampling is applied to reduce the readout noise. This is one of the biggest advantages of off-chip amplifiers.

Quantum Efficiency

The quantum efficiency was determined by varying the temperature of a blackbody and observing the photon response of the detector for different levels of photon flux. The filter transmission curve used to derive the photon flux was measured at liquid nitrogen temperature. The pixel transfer function needed to convert the detector signal to electrons was obtained by the standard shot noise method. Engineering grade array: The cut-off wavelength of a first engineering grade array was measured to be \( \lambda_c = 2.58 \) mm. Since the dark current of the engineering grade array was higher than expected and showed a temperature dependence which yields an effective temperature being one third of \( T_{eff} = E_g/2K_b \), the sensitivity of the array was investigated at wavelengths longer than \( \lambda_c \). A narrow band filter centered at \( l = 3.22 \) mm was mounted in the test camera and the quantum efficiency at \( l = 3.22 \) mm was determined to be 1.1 \( 10^{-5} \). In order to exclude the existence of filter leaks and to confirm the
spectral response at $l=3.22$ mm, the transmission of the narrowband filter was measured with the engineering array using a scanning grating monochromator. As the photon response was confirmed by the measurement, an extrinsic transition from impurity donors to the conduction band in the multiplexer, the buffer layer or the diode array must be assumed to generate the excess dark current.

Science grade array: The quantum efficiency of the science grade array is above 0.68 over the whole spectral range of the detector and peaks in K-band at 0.84. The wavelength dependence of the quantum efficiency was measured with a grating monochromator. The efficiency of the monochromator was calibrated with a pyroelectric detector which is assumed to be spectrally flat. The accuracy of the measurement shown below is limited by the sensitivity of the pyroelectric detector. The cutoff wavelength is $\lambda_c=2.6$ mm. The Hawaii2 science grade array has the highest QE of all LPE arrays ever evaluated at ESO.
Dark current

The detector was blinded by a black aluminium cover. Since the detector is cooled by the central pins of a pin grid array (PGA) package, great care was taken to calibrate the detector temperature and take into account the temperature gradient between the cold finger and the detector. In a separate experiment a temperature sensor was mounted on an empty PGA carrier and cooled to measure this temperature gradient.

For the science grade array the temperature dependence of the dark current yields the correct effective temperature $T_{\text{eff}} = 2360 \, \text{K}$. The dark current is 0.004 e/s at 60K and 0.20 e/s at 79.1K. The cosmetic quality degrades substantially by raising the temperature form 60K to 79 K as can bee seen by the dark exposures shown here.

![Dark exposure of Hawaii2 LPE science grade array at $T = 79 \, \text{K}$ (left image) and $T = 60 \, \text{K}$ (right image). Scale min = -0.025, max = 0.25 e/s/pixel. Detector integration time 4 hours. Mean dark current at $T=79 \, \text{K}$: 0.2 e/s/pixel. Mean dark current at $T = 60 \, \text{K}$: 0.004 e/s/pixel.](image)

Dark current versus temperature for MCT LPE and MBE arrays and different cutoff wavelengths.
The final arrays which will be installed in NIRMOS will be double layer planar heterostructure MBE arrays grown on CdZnTe substrate. The cut-off wavelength of these arrays will be \( \lambda_c = 1.9 \) mm. A smaller format engineering array grown by this technology was hybridized to a PICNIC 256x256 multiplexer and has already been tested at ESO in order to validate the continuous flow cryostat for infrared applications (NIRMOS). The MBE array shows excellent dark current performance. At a temperature of 100 K the dark current scaled to a pixel size of 18 mm is 0.008 e/s. The persistence is strongly reduced in comparison to LPE grown MCT material demonstrating the potential of MBE on CdZnTe. Further tests with a science grade MBE array will be carried out. Finally, the PICNIC array will be installed in FINITO, the fringe sensor of the VLT interferometer, where it will operate as part of an active control loop.

**Readout Noise and Glow**

The readout noise has been measured with the unbuffered output reading out all 32 channels. The time required to read out a full frame is 600 ms. The readout noise for double correlated sampling is 12 electrons rms. With multiple nondestructive sampling using 16 Fowler pairs the readout noise can be reduced to 5.2 electrons rms. In the best quadrant the readout noise is as low as 4.4 erms. The glow of the Hawaii2 multiplexer is substantially reduced in comparison to the Hawaii1 multiplexer. At the last row of each channel close to the edges of the array the glow is 1.5 electrons/frame and peaks in the corners to 3 electrons/frame. The glow is negligible at a distance of 30 pixels from the edges.

**Problems with Hawaii2**

Although in most respects the Hawaii2 science grade array exhibits excellent performance, there are some problems associated with the Hawaii2 multiplexer.

- Interleaved clocking of the fast shift register is not possible. The 4 clocks of the fast shift register have to be pairwise complementary (CLK1 with CLK2, CLKB1 with CLKB2) and skewed to less than 50 ns. If several arrays have to be read in parallel using one single clock driver, these clocks should be generated on the fan-out board using CMOS buffers (HEF 4041)
- Use of the reference outputs requires four additional video channels or a cryogenic clamp circuit for the symmetrical cryo-opamps. The reference output is not available for the unbuffered output mode.

Consequently, Rockwell redesigned the Hawaii2 multiplexer. All MBE 2Kx2K arrays presently on order by ESO will be delivered with the resulting new Hawaii-2RG multiplexer.