The CRIRES InSb megapixel focal plane array detector mosaic

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ABSTRACT

For the high-resolution IR Echelle Spectrometer CRIRES (1-5 μm range), to be installed at the VLT in 2005, ESO is developing a 512 x 4096 pixels focal plane array mosaic based on Raytheon Aladdin III InSb detectors with a cutoff wavelength of 5.2 microns. To fill the useful field of 135 mm in the dispersion direction and 21 mm in the spatial direction and to maximize simultaneous spectral coverage, a mosaic solution similar to CCD mosaics has been chosen. It allows a minimum spacing between the detectors of 264 pixels. ESO developed a 3-side buttable mosaic package for both the Aladdin II and Aladdin III detectors which are mounted on multilayer co-fired AlN ceramic chip carriers. This paper presents the design of the CRIRES 512 x 4096 pixel Aladdin InSb focal plane array and a new test facility for testing mosaic focal planes under low flux conditions.

Keywords: IR Detectors, FPA, mosaics, CCDs, packages, AIN, detector testing

1. INTRODUCTION

CRIRES is a cryogenic high-resolution IR spectrograph for the ESO VLT [1, 2, 3]. It fills a gap in the resolving power-wavelength parameter space of the present VLT instrumentation. The instrument extends the VLT high-resolution spectroscopic capabilities into the infrared out to 5.2 µm. High spectral resolution (up to R=100,000), large simultaneous wavelength coverage and high sensitivity were primary design goals. It can boost all scientific applications aiming at fainter objects, higher spatial, spectral and temporal resolution. This IR spectrograph will make previously inaccessible phenomena and objects available for spectroscopic studies. A picture of the optical layout can be seen in Figure 1. CRIRES is an reflective cryogenic echelle spectrograph for the Nasmyth focus A of the ANTU VLT telescope. The desired large spectral coverage is realized through four large infrared detectors arranged in the focal plane along the main dispersion direction. The spectral resolving power is R=100.000 with 2 pixel sampling at all wavelengths. CRIRES is a stationary instrument fed via a curvature-sensing Adaptive Optics system for light concentration on the narrow entrance slit of a 0.2 arcsec.

Functionally, the CRIRES instrument can be divided into four units:

- The fore-optics section for field de-rotation, curvature sensing adaptive optics and slit viewing, cold pupil and field stops.
- The prism pre-disperser isolates one echelle order and minimizes the total amount of light entering into the high-resolution section.
- The high-resolution section comprises the collimator, the echelle which is tilt-tuned for wavelength selection, the camera providing the 0.1 arcsec/pixel plate scale, and the detectors.
- The calibration unit outside the cryogenic environment contains light sources for flux/wavelength calibration and detector flatfielding.

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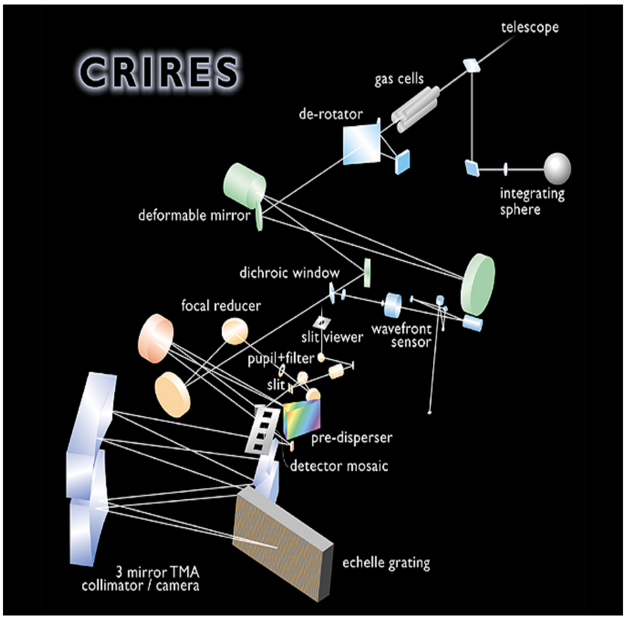

Figure 1 Optical layout of the CRIRES instrument

2. DESIGN OF THE CRIRES INSB MEGAPIXEL FOCAL PLANE ARRAY

The CRIRES detector system uses 5 Raytheon 1024 x 1024 pixel InSb Aladdin arrays, one for the slitviewer camera and four in the spectrograph focal plane. To fill the useful field of 135 mm in the dispersion direction and 21 mm in the spatial direction for the spectrograph focal plane and to maximize simultaneous spectral coverage, a mosaic solution similar to CCD mosaics has been selected. It reduces the minimum spacing between the detectors to 264 pixels and will ensure a intrinsic stability of 1/20 of a pixel required for the instrument.

2.1 A new 3 side buttable package for the Aladdin II and Aladdin III FPA

The standard packages for the Raytheon Aladdin arrays are LCC packages which cannot be used to build close buttable mosaics. In order to reduced the gap between arrays, the CRIRES Aladdin detectors mounted in this standard leadless chip carrier were removed from the original package and then assembled onto a new ceramic board developed by ESO. ESO and Raytheon collaborated on this new 3 side buttable package for the Aladdin II and III detectors. ESO developed the multilayer co-fired AlN ceramics carrier and an invar base plate for mounting and Raytheon glued the detectors onto the ceramics and did the bondwiring.

Figure 2 Pictures of the invar baseplate with the copperblock, the 8 layer AlN ceramics and the final mounted Aladdin device

This new package includes an invar package base, a copper block for braid/cooling connection, a 3-point kinematic mount, the AlN ceramic chip carrier, a NANONICS 65 pin miniature connector and an integrated temperature sensor and heating resistor. The basic material properties of the AlN ceramics are high thermal conductivity (160 W/mK) and a thermal coefficient of expansion matching that of the silicon multiplexer . Hot press technology with precision tolerances (0.1%) for manufacturing is used. A Tungsten (0.15 ohm/sq) metallization is used for the tracks. The bondpads and connector pads were put onto the ceramics via thin film technology. Pictures of the invar baseplate, the ceramics and the final detector are seen in Figure 2. Figure 3 shows details of the 8 layer AlN ceramics with internal interconnects and bonding pads.

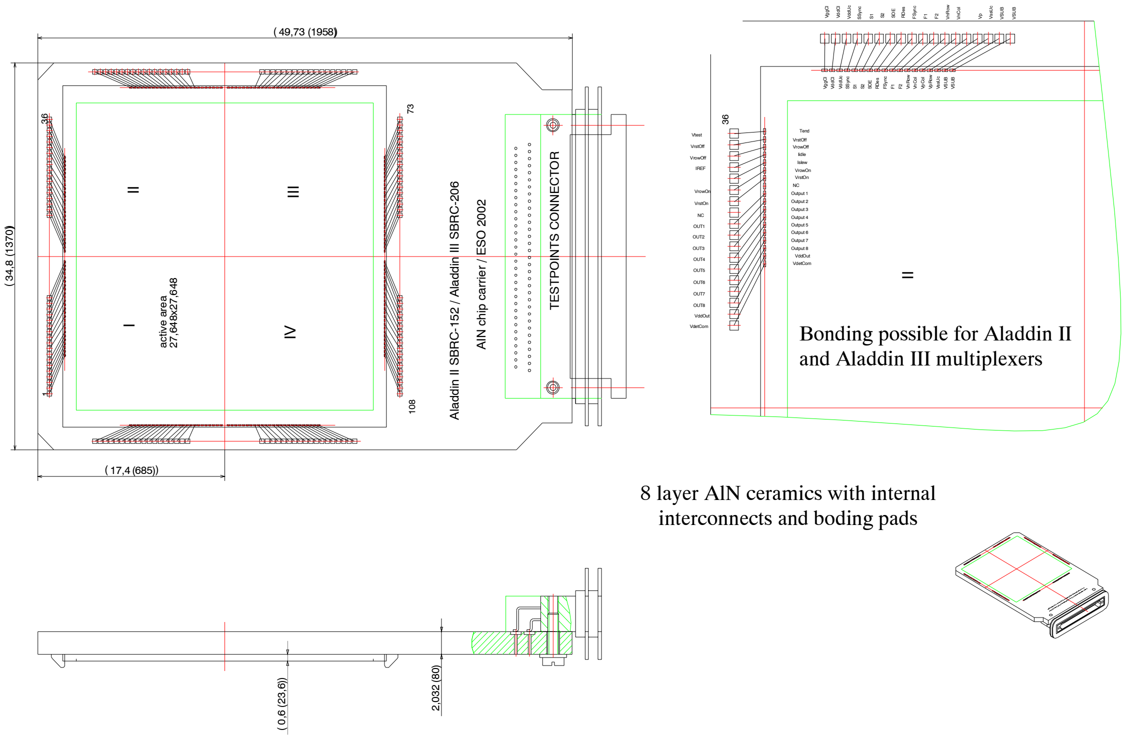

Figure 3 Layout of the 8 layer AlN ceramics with internal interconnects and boding pads

The re-packaging of all four Aladdin arrays has recently been completed and the first 3 arrays have been tested at ESO for dark current and readout noise. Unfortunately, an old Aladdin II, which was forseen as the fourth detectors had a thinner substrate than the Aladdin IIIs and was broken during the repackaging process. This array was outstanding due to its extremely low dark current of 14 electrons/hour at 25 K. It has recently been replaced by an Aladdin III array to complete the mosaic. This array is right now under tests at ESO and awaiting final acceptance.

2.2 Design of the detector setup for the science focal plane

The CRIRES science focal plane consists of four Aladdin III arrays. As the slit is only 512 pixels long we do not require 4 useable quadrants per array and have thus saved money by buying ërejectí arrays with one or more defect quadrants. Two quadrants of each array are used to cover the useful optical field indicated by the rectangle in Figure 4. Since most of the individual arrays have only two adjacent science grade quadrants, the arrays needed to be mounted in different orientations. A two layer flexible manganin-board interfaces the detector to the multilayer flex-rigid daughter board housing filters for clock and bias voltages, antistatic protection and 64 cryogenic preamplifiers. In the vicinity of the detector, the detector board is also cooled to cryogenic temperatures. The amplifiers have to operate at temperatures above 60 K but should be placed as closely as possible to the detector, which has to be cooled to 30 K. The detector is well baffled from thermal radiation emitted by the preamplifiers and load resistors on the daughter board in a light tight box. The flexible manganin-board will also maintain the temperature gradient between the detector and the preamplifiers. Light tight connectors at the second radiation shield block room-temperature photons. Two separate flex-rigid cables for video- and bias/clock-voltages connect the detector board with the vacuum feed-through connectors. Figure 5 shows the layout of the final mosaic and pictures of the detector mosaic, the manganin cable and detectorboard with the light tight aluminum box.

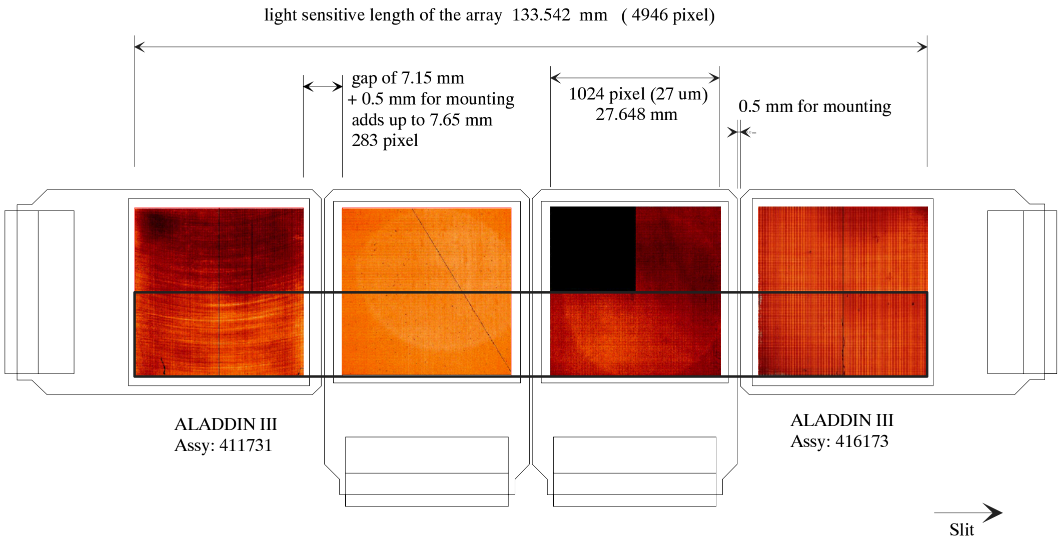

Figure 4 Layout of the final CRIRES science array mosaic

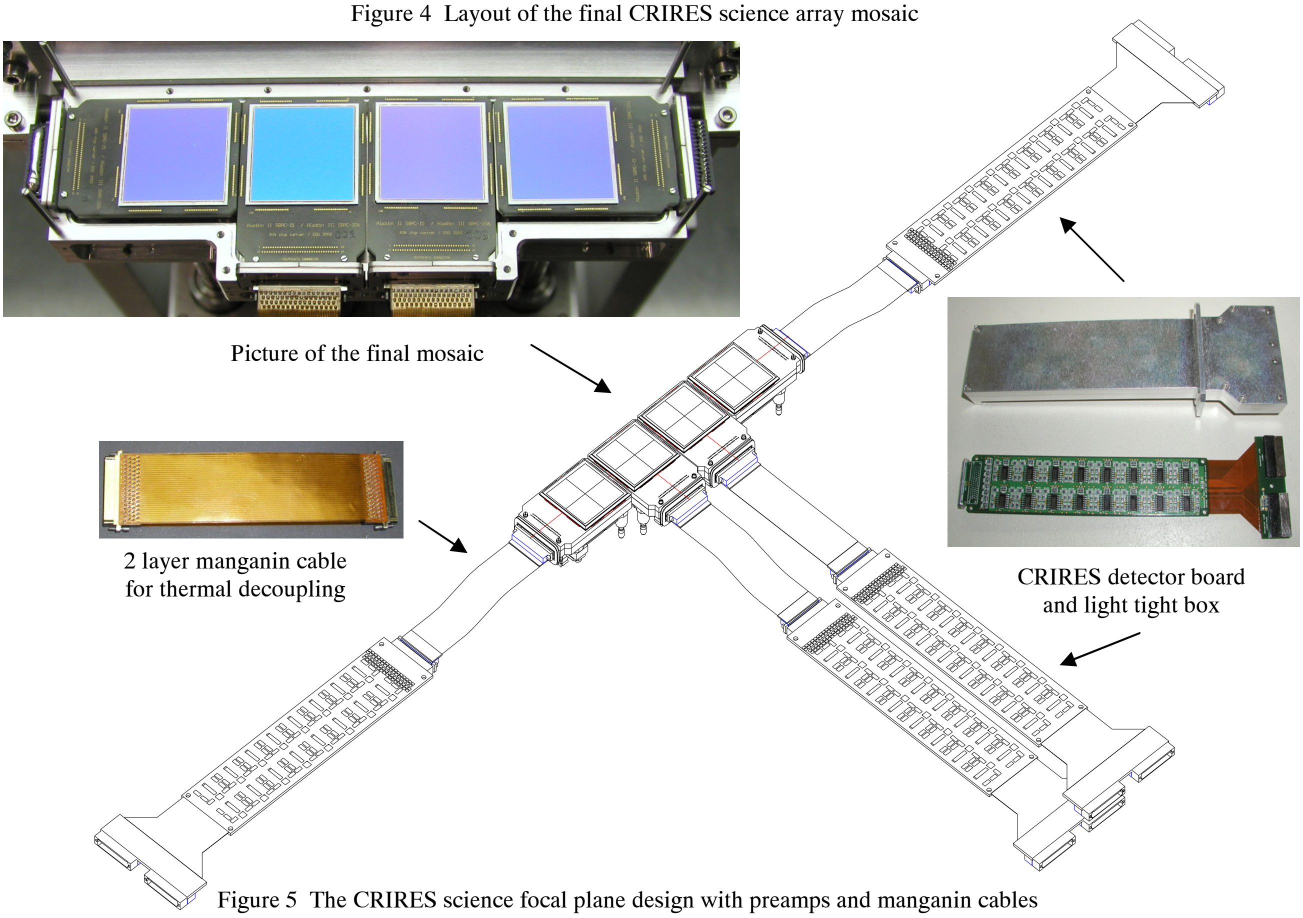

Figure 5 The CRIRES science focal plane design with preamps and manganin cables

2.3 Design of the detector setup for the slitviewer camera

Since in the slit viewing camera low darkcurrent is not as important as good cosmetic quality, one of the remaining arrays from the ESO Aladdin II foundry run has been selected. The array ALIRD06 was the best choice. It has a darkcurrent of 25 e/sec and two cracks, but all four quadrants are operational (Aladdin II SBRC-152 multiplexer).

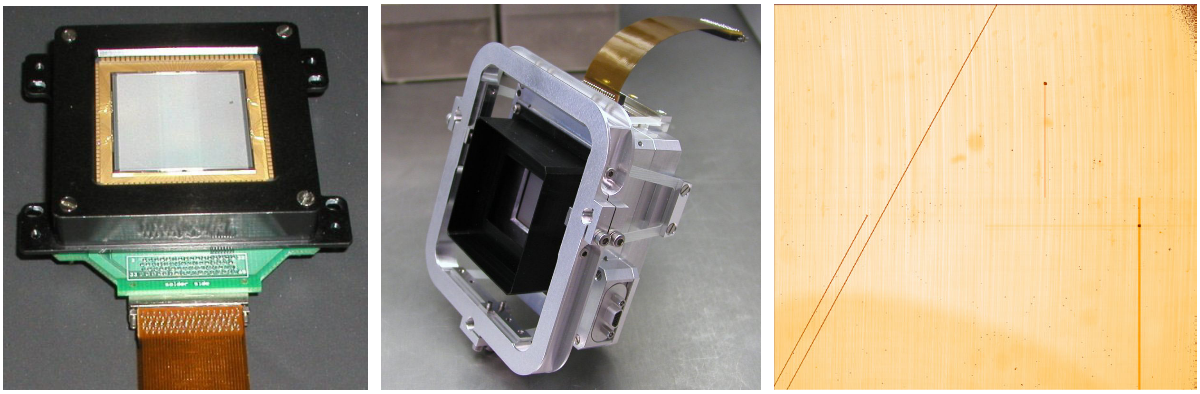

Figure 6 -Slit viewer detector setup and detector mount, ALIRD06, QE H-band =0.54

Since there was no need to put this detector onto a buttable package it remained in the LCC package and a detector board was designed to mach the interface to the manganin cable used for the other arrays. Figure 6 show this detector setup with a bare multiplexer, the mechanical detector mount and a raw flatfield taken with the device.

2.4 Detector characteristics

For the CRIRES detector system, the Aladdin II detector foreseen for the slitviewer has been fully tested and is well suited. The temperature drift of the video signal for Aladdin arrays is 1700 electrons/ K. A temperature stability in the micro Kelvin range is required without drift compensation. With our versatile high speed data acquisition system (IRACE) the readout noise of Aladdin arrays could be reduced to below 10 electrons rms by application of multiple nondestructive readouts and subpixel sampling of the analog signal. Double correlated: < 40 electrons rms. The QE has been measured to be in J=89%, H=73%, K=88%, L=68% and M=74 % bands (see Finger et al, 2002) [3,4]. Up to now three detectors for the science focal plane have been tested individually. Dark current and read noise was measured after the repackaging process and met all specifications required for CRIRES. The dark current (30 K, Vbias=0.5V) is below one electron/sec and the readout noise is between 8-10 electrons for Fowler sampling and between 30 to 40 electrons for a normal double correlated readout.

3. A NEW DETECTOR MOSAIC TEST FACILITY

To test the CRIRES focal plane array a new detector mosaic test facility is under development at the ESO IR laboratory. This facility is a major development and will first serve as the test cryostat for CRIRES and later for other mosaics. Most components of this test facility will be used for future projects. To test the CRIRES mosaic requires frequent assembly and disassembly with additional handling of the science arrays exposing them to considerable risk. Therefore the testing should not be carried out in the final CRIRES instrument. In the mosaic test facility a large variety of key issues affecting the performance of the focal plane can be addressed such as:

- Functionality of the mosaic
- Detector dark current measurements versus detector temperature
- Testbed for low flux applications
- Test of the clamp circuit of the Aladdin multiplexer to emulate reference pixels for suppression of low frequency noise and signal drifts

- Measurement of instrumental photon background
- Optimization of radiation shielding for cable feedthroughs
- Cryogenic performance of the mosaic
- Quantum efficiency in H, K, L and M
- Uniformity and cosmetic quality of mosaic
- Analog bandwidth of video output
- Crosstalk and electronic ghosts
- Electroluminescence

In CRIRES, which has a spectral resolution of R = 100000, a 0.2 arcsec slit, a pixel scale of 0.1 arcsec/pixel and an overall system efficiency of 30 %, the continuum emission generates a photon current of 1.3 x 10-3 e-/s/pixel. Since the lowest detector dark current measured with InSb is 4 x 10-3 e-/s/pixel at an operating temperature of 25 K, the dark current will always dominate the signal generated by the continuum emission between the OH-lines of the J-band. The detector system will be limited by the detector dark current, provided that the instrumental photon background for both the test facility and CRIRES can be kept lower than the detector dark current, which is the main goal to be achieved.
The primary goal of the CRIRES detector mosaic test facility is to develop, test and assess the functionality and the performance of the assembled Aladdin focal plane mosaic. After successful completion of this task the tested components will be transferred to CRIRES and the prime focus of testing will shift from the detector to the evaluation of the instrument performance. No image quality tests will be performed in the mosaic test facility, since the field is too large and the required optics would exceed the scope of a test facility.

Therefore a simple blackbody and a pinhole grid mask in front of the detector will be used without any optics to generate a photon response on selected areas of the detector. Since all detector tests have to be carried out under extremely low photon backgrounds of <0.1 photon/s/pixel, no cryostat window will be used and the blackbody will be contained inside the hermetically sealed, radiation tight cold structure.

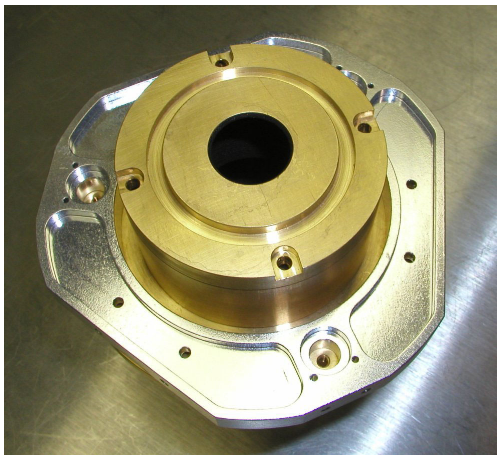

Figure 7 Picture of the cryogenic blackbody with a aperture of 20 mm.

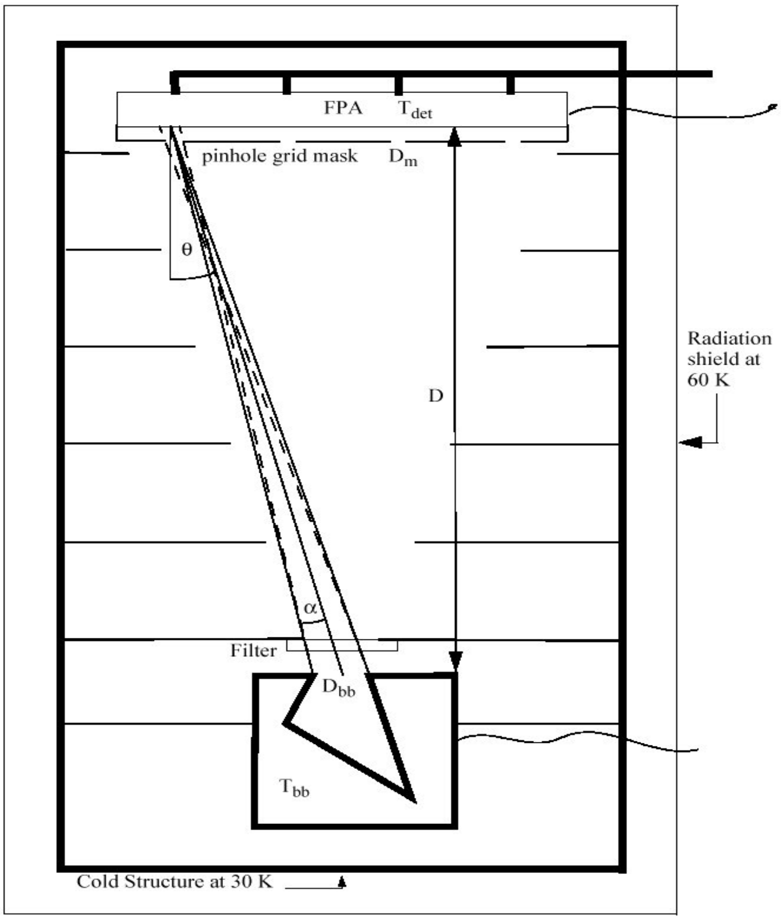

Figure 8 Schematic layout of the detector mosaic test facility

The detector, the blackbody and optical baffles are enclosed in the cold structure cooled to a temperature of 30 K. The blackbody is supported inside the cold structure by a thermally isolated epoxy spider at a distance of 200 mm from the focal plane. The blackbody has an aperture of 20 mm and can be covered by 1 inch filters mounted on a filter wheel. The maximum angle between the incident beam in the corners of the mosaic and the optical axis is 18 degrees. The mosaic can be uniformly illuminated with the intensity variations across the array due to oblique incidence of less than 5%. The focal ratio at the detector is f/10. If the detector temperature can be varied from 60 to 150 K, the quantum efficiency of the complete mosaic can be measured for L- and M-band. If the maximum blackbody temperature is 300 K the quantum efficiency in K- and H-band can be measured as well. Figure 7 shows a picture of the blackbody.

At a distance D of 500 mm in front of the focal plane an exchangeable pinhole grid mask is mounted, which allows to illuminate selected regions of the focal plane by a calibrated photon flux. All feedthroughs for electrical detector interfaces, cooling braids and temperature controls are original CRIRES parts and can be tested in this setup prior to installation in CRIRES. The detector is cooled to 30 K by the second stage of a closed cycle cooler. The blackbody, the optical baffles and one filter are enclosed in the cold structure, which is connected to the first stage of the closed cycle cooler and cooled to a temperature of 60K. Picture 8 shows a schematic drawing of the layout of the testfacility and Figure 9 a picture of the facility in the current status of development.

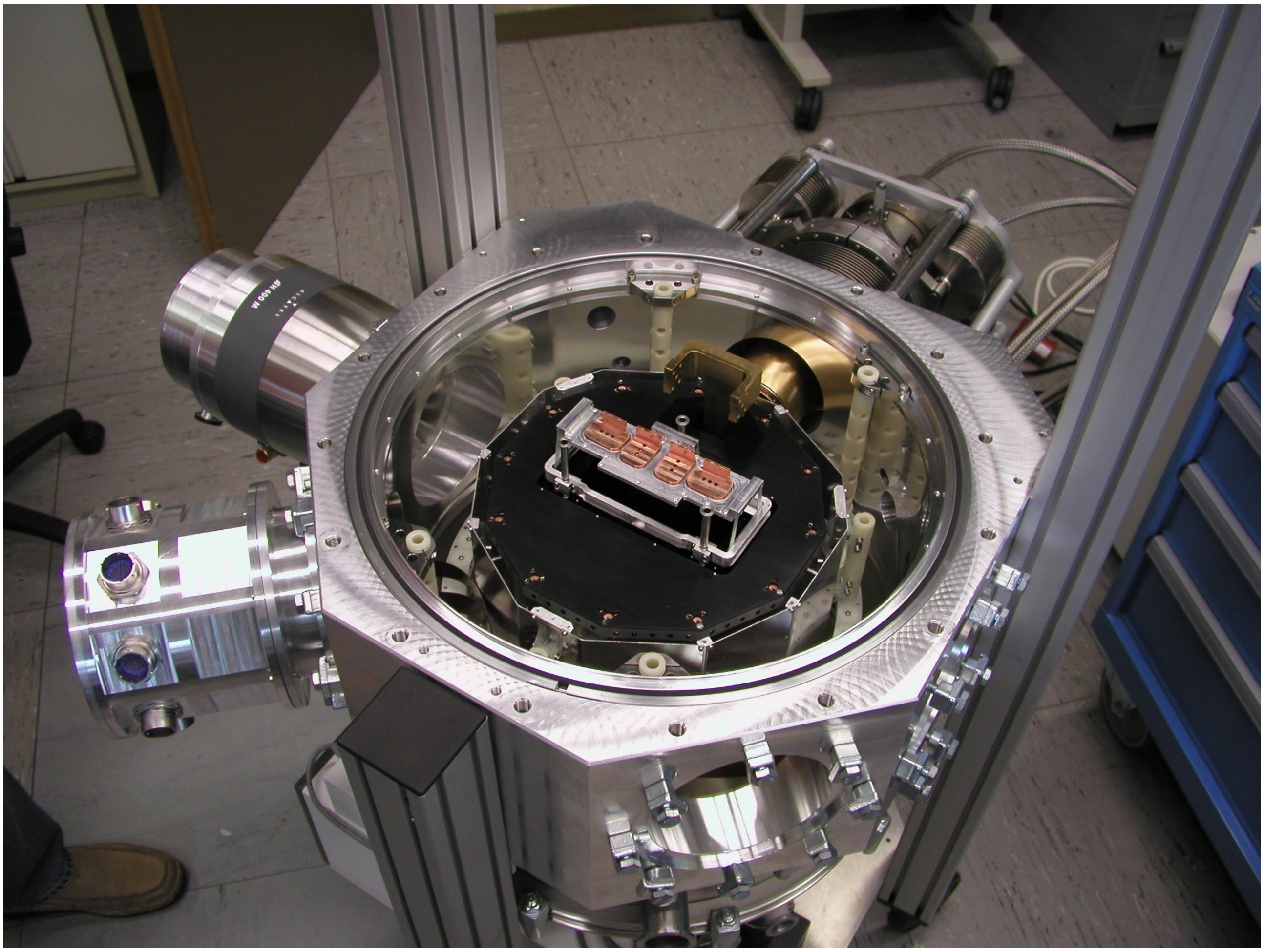

Figure 9 Picture of the current development status of the mosaic test facility.

In the middle the mechanical mounting structure for the CRIRES mosaic can be seen. The blackbody will illuminate the array from the bottom side of the cryostat (no seen in the picture) Top right the closed cycle cooler with the cooling connection and top left the vacuum pump and the vacuum connectors for the detectors are seen.

4. THE CRIRES DETECTOR CONTROLLER SYSTEM IRACE

The data acquisition system of CRIRES will be the ESO standard Infrared Detector High Speed Array Control Electronics, IRACE. It will consist of two separate units. One system will simultaneously read out all four 1Kx1K InSb Aladdin science arrays to retrieve the spectrum of CRIRES (128 parallel channels). The second IRACE system will read out one Aladdin array placed in the focal plane of the slit viewing camera (32 parallel channels). The IRACE system for the slit viewer has to read out the single 1K x 1K InSb detector at frame rates up to a few 100 Hz depending on the size of the subwindow because one needs to observe very bright stars up to a magnitude of -2 to -4 in k-band. During long time exposures for acquisition of the spectrum the slit viewing detector will track the position of the science object. After background subtraction it will determine a shift vector every two seconds and send this vector to the observing software for tip-tilt correction. Even though the ADC speed is slow (500 KHz) and the maximum read speed per pixel is 2µs, the readout time for the full frames of all three 1Kx1K arrays is 65 ms due to the multiplex advantage of the128 parallel video channels. A picture of an IRACE 128 channel data acquisition system is shown in Figure 10. The data transport (gigalink) and communication (TIF) to front end is done by a gigabit fiber optic link connected to a custom made PCI card which forms the backend of the system together with a 19 inch rack mountable PC with two Intel-Xeon 3.0 GHz processors and a system bus of 400 MHz (FSB). For more details on IRACE see Meyer et al, 1996, [4].

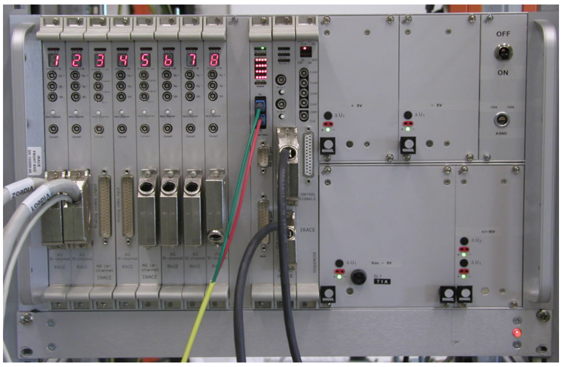

Figure 10 Front end electronics with 128 ADC channels, sequencer and clock drivers

5. CURRENT STATUS AND OUTLOOK

The CRIRES instrument is currently integrated at ESO and is planned to be installed at the telescope in the first quarter of 2005. The IRACE detector acquisition electronics and software are being tested and the integration and test of the complete mosaic will soon be starting in the newly developed mosaic test facility.

6. REFERENCES

1. Moorwood, A.F.M. et al, (2003) CRIRES takes shape, In: The ESO messenger No. 114, pp. 5-9, 2003
2. Moorwood, A.F.M. et al, (2002), CRIRES: a high-resolution infrared spectrograph for the VLT, In: Instrument Design and Performance for Optical/Infrared Ground-Based Telescopes, Waikoloa, Hawaii, August 2002, Proceedings of SPIE, vol. 4841
3. K‰ufl, H-U et al, (2004), CRIRES: a high-resolution infrared spectrograph for ESO's VLT, these proceedings
4. Dorn, R.J., Meyer, M., Finger, G., Mehrgan, H., Moorwood, A. F. M., Stegmeier J., (2002), In: Scientific detectors for Astronomy, Waimea, Hawaii June 2002, Kluwer Academic publishers
5. Finger, G., Dorn, R.J, Hoffman, A.W., Mehrgan, H., Meyer, M., Moorwood, A.F.M., Stegmeier, J., (2002), Readout techniques for drift and low frequency noise rejection of infrared arrays, In: Scientific detectors for Astronomy, Waimea, Hawaii June 2002, Kluwer Academic publishers
6. Finger, G., Dorn, R.J, Mehrgan, H., Meyer, M., Moorwood, A.F.M., Stegmeier, J., (2002), Test results with 2Kx2K MCT arrays, In: Scientific detectors for Astronomy, Waimea, Hawaii June 2002, Kluwer Academic publishers
7. Meyer, M., Finger, G., Mehrgan, H., Moorwood, A. F. M., Stegmeier, J. (1996), The ESO Infrared Detector High-Speed Array Control and Processing Electronics IRACE, In: The ESO messenger 86, pp.14-17