e2v CCD and CMOS sensors and systems designed for astronomical applications

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ABSTRACT

e2v continues to evolve its product range of sensors and systems, with CCD and CMOS sensors. We describe recent developments of high performance image sensors and precision system components. Several low noise backthinned CMOS sensors have been developed for scientific applications. CCDs have become larger whilst retaining very low noise and high quantum efficiency. Examples of sensors and sub-systems are presented including the recently completed 1.2 GigaPixel J-PAS cryogenic camera.

Keywords: CCD, CMOS, sensor, EMCCD, backthinned, FPA, cryogenic camera system

1. INTRODUCTION

In this paper we describe progress on several important developments of both sensors and systems for astronomy. The common theme is that of high performance and reliable manufacture. In a previous paper[1] we described selected sensors and many of these have now completed development. The e2v web site[2] provides datasheets for those sensors that are considered production devices; in other cases sensors are provided to custom order. In all cases e2v executes design, manufacture, assembly and test in-house (only using outside foundries for its CMOS products).

2. CMOS SENSORS ACHIEVE MATURITY

e2v designs and manufactures CMOS sensors for space, astronomy, and commercial markets. Most of these are backthinned and have low noise for high sensitivity. The following sections illustrate some recently developed sensors, many of which are now given identifying names (rather than just part numbers).

2.1 CIS113 (Vega)

The TAOS-II project requires a large area mosaic sensor capable of 20 fps readout with multiple regions-of-interest in order to detect Trans-Neptunian-Objects by occultation. The Vega device is a 3-side buttable CMOS (APS) sensor to allow a large focal plane capable of the required readout rate. Ten sensors will form the complete focal plane assembly (FPA) and three telescopes each with their own FPA will be built. Another paper describes the prototype cameras[3]. The figures below illustrate the device and the spectral response (of the backthinned sensor).

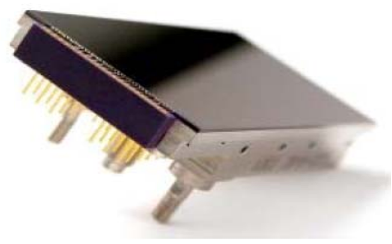

Figure 1. Backthinned Vega sensor in buttable package

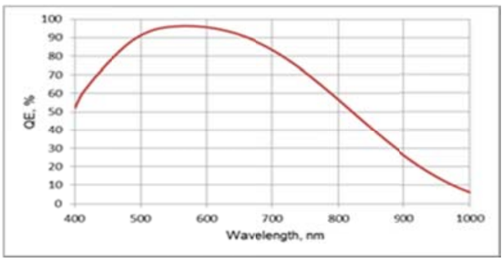

Figure 2. Spectral response of Vega

The development phase is now complete and the production phase (for the set of 40 sensors is underway) with completion expected early in 2017. Outline details are presented below and more details of the sensor are presented in another paper[4].

Table 1. Summary information

Number of pixels	1920 (H) × 4608 (V)
Pixel size	16.0 µm square
Image area	73.728 mm × 30.72 mm
Output ports (each with REF and SIG)	8
Package size	82.39 mm × 31.7 mm
Package format	76 pin ceramic pin grid array attached to invar block
Focal plane height, above mounting surface	14.0 mm
Flatness	< 30 µm (peak to valley)
Conversion gain	75 µV/e^-
Readout noise	3 e^- at 2 MP/s per channel
Maximum pixel data rate	2 MP/s per channel
Maximum charge per pixel	22,000 e^-
Dark signal	70 e^-/pixel/s (at 21 °C)
Frame rate	2 fps in full frame mode; 20 fps with multiple ROI's

2.2 CIS112 (NGSD)

Adaptive optics for the new generation of extremely large telescopes requires correspondingly large sensors together with high frame rate. Since only CMOS architecture (rather than CCD) can provide a large number of pixels and high frame rate e2v has developed a high performance backthinned CMOS sensor designed originally for Natural Guide Star use. This sensor is the precursor of an intended larger device of four times the area. The sensor has very low read noise for high sensitivity.

The "NGSD" CIS112 sensor is illustrated below.

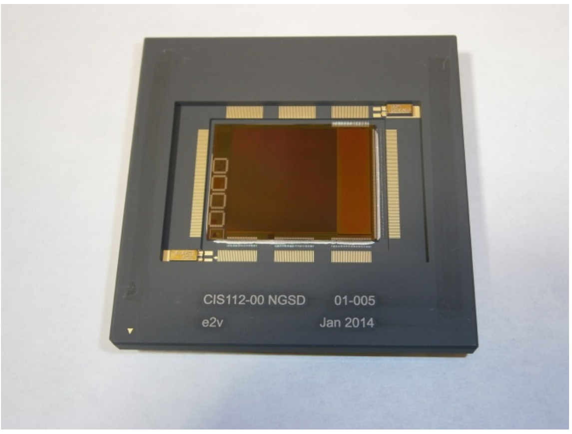

Figure 3. 880 X 840 CIS112

Only minimal information is presented here, since another paper[5] describes the sensor more fully.

Table 2. Summary information

Number of pixels	880 X 840
Pixel size	24.0 µm square
Image area	21.12 mm × 20.16 mm
Output	Digital; multiple parallel ADCs
Package format	Ceramic PGA
Readout noise	3 e^-
Variants	> 85% at 589 nm
Maximum charge per pixel	4,000 e^-

2.3 Onyx EV76C664

This sensor is sold by e2v as a standard product for commercial applications. However since it has low noise can be of interest for astronomical use. Full details of this sophisticated digital sensor are available on the datasheet[2]. Summary information is shown below.

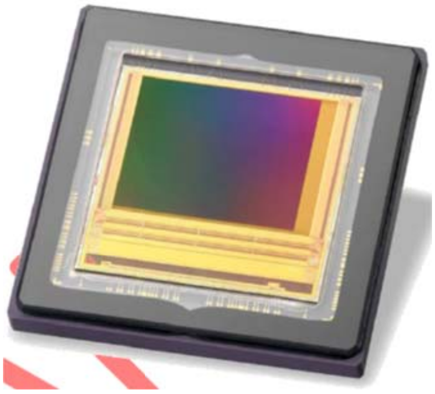

Figure 4. Onyx 1.3 MegaPixel sensor

Table 3. Summary description of Onyx sensor

Number of pixels	1280 X 1024 (1.3 Megapixel)
Pixel size	10.0 µm square
Shutter modes	Global and Rolling
Output	8, 10, 12, 14 bit LVDS
Package format	Ceramic 67-pin PGA
Readout noise	6 e^- (min, depending on mode)
Quantum Efficiency	Monochrome or sparse colour (with microlens)
Maximum charge per pixel	16,000 e^-

2.4 CIS115 (Sirius)

This sensor is also backthinned, offers low read noise, and has been developed for space applications, including the ESA JANUS (Juice) mission. It is currently being qualified for space use. Initially sample quantities are being supplied, with further quantities of Flight Models to follow, with parameters as presented below. Radiation tests, endurance, storage temperature, thermal cycling, and shock & vibration tests are underway with results expected by end-2016.

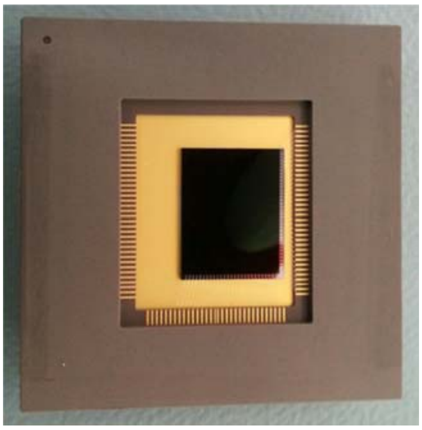

Figure 5. Sirius sensor

Table 4. Summary of Sirius features

Number of pixels	1504(H) × 2000(V)
Pixel size	7.0 µm square
Number of output ports (reset and signal pins)	4 pairs of analogue outputs
Package size	48.26 mm square
Package format	140 pin ceramic pin grid array
Flatness	< 10 µm (peak to valley)
Conversion gain	35 µV/e^-
Readout noise	7 e^- (Rolling shutter)
Maximum pixel data rate	8 MP/s per channel
Maximum charge per pixel	55,000 e^-
Frame rate	Up to 10 Hz
Minimum time to read and readout one line at 6·2 MP/s	66.25 µs
Frame rate at full resolution	Up to 7.5 fps

2.5 TDI CMOS development

As another strand of CMOS imager development, e2v is in the process of building such sensors with TDI (Time-Delay-Integrate) architectures. TDI CCDs are commonly used for scanning applications in space such as the GAIA telescope. The addition of TDI to a CMOS imager allows increased sensitivity together with the advantages of a digital architecture and low power consumption. See IISW 2015 paper "CMOS Charge transfer TDI with front side enhanced quantum efficiency" by F Mayer on e2v web site[2].

Several techniques have been reviewed and the most promising technique appears to be making a CCD-like structure to allow charge summation along the track. An important issue is achieving good charge transfer especially after irradiation (as required for space use). Small test devices have been manufactured and characterized after irradiation; these show good promise and the next step will be to design a full-sized device (including high-speed ADC). See figures below.

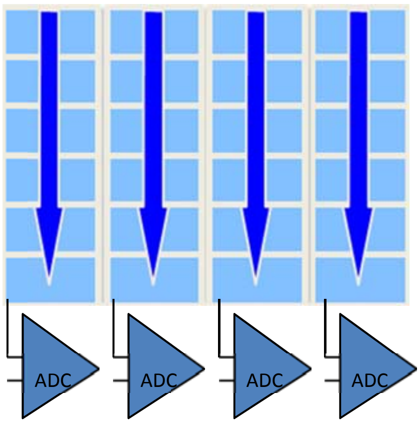

Figure 6. Charge summation along pixel

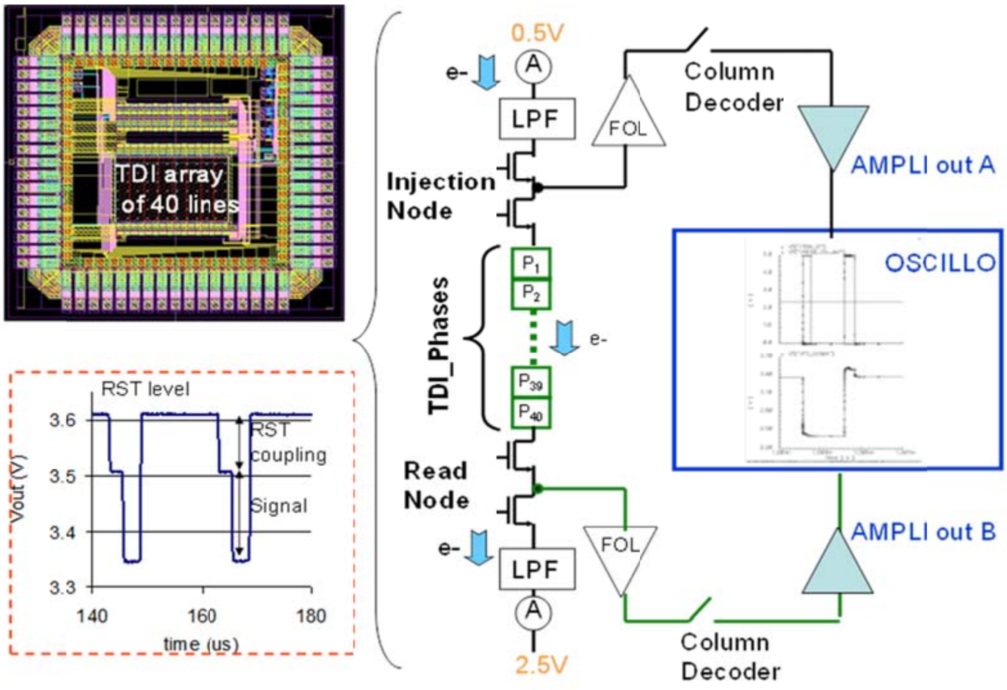

Figure 7. Concept of TDI CMOS (test device)

2.6 CIS111 (MTG FCI)

This is an example of a CMOS imager designed for earth observation where it offers higher frame rate and less crosstalk than an equivalent CCD.

The CIS111 is to be used on the Meteosat Third Generation Flexible Combined Imager. It has 5 independent imager blocks with in-package filters. Outer blocks have rhombus-shaped pixels. CVF values vary from 0.8- 8 µV/e- to suit illumination level. Charge transfer paths are optimized to speed transfer through the large pixels and avoid lag. See figure below.

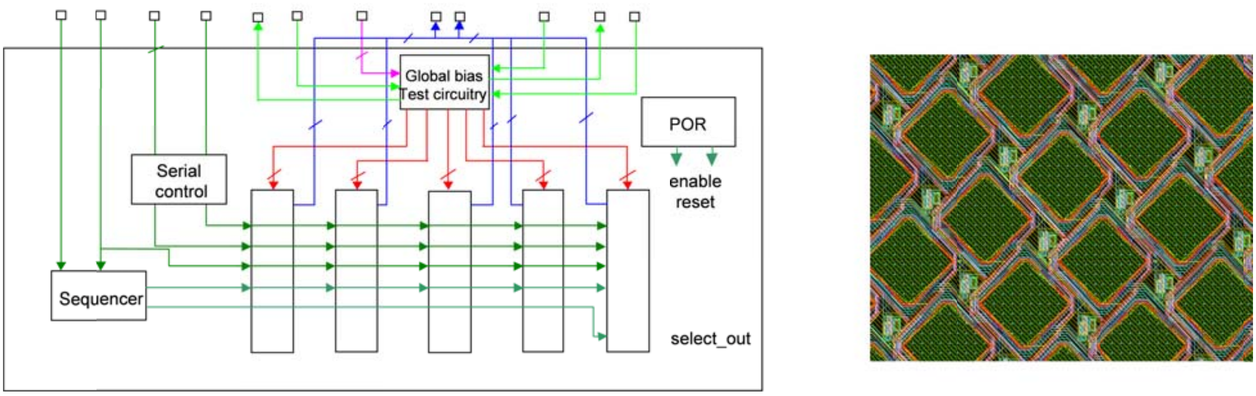

Figure 8. CIS111 architecture

2.7 CIS116 (Metimage)

Another custom test vehicle is the CIS116 which has 250 µm square pixels each one of which has 8 photodiodes with a common sense node. The main target is to optimize lag and CVF with variants of transfer gates and photodiode shape. Peak signal is 2.5 Me- with 84 dB dynamic range. Designed for backthinning. The test device has recently been characterized. See illustration of pixel below.

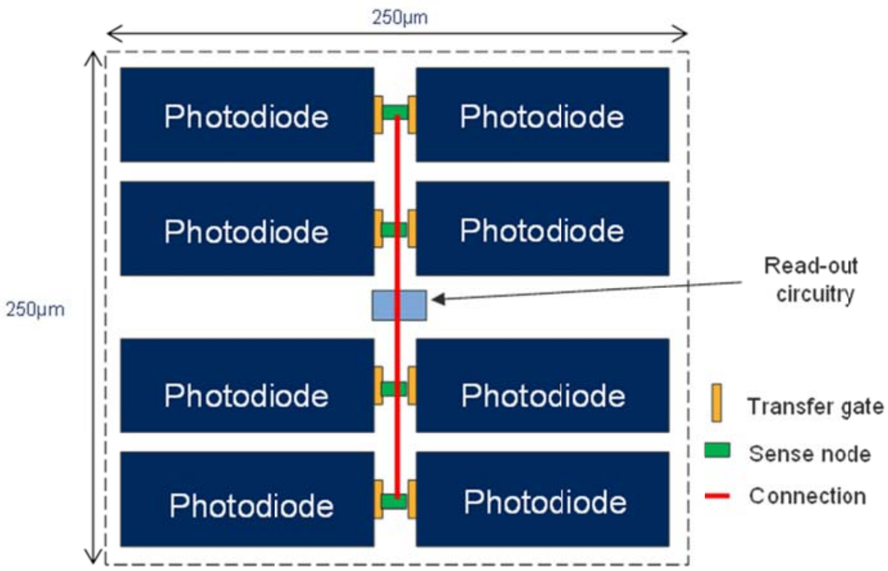

Figure 9. CIS116 pixels

3. CCD SENSORS

In this section we illustrate selected sensors with particular features of current interest to astronomers. Many other sensors can be seen on the e2v web pages[2]. Here we describe several EMCCDs offering exceptionally low noise together with traditional CCD performance in terms of uniformity and high spectral response. e2v also manufactures a range of standard backthinned sensors with very low noise and formats ranging from 1K X 1K up to 9K X 9K. e2v continues to specialize in design and manufacture of a wide range of custom sensors designed for space applications; many of these recent ones were illustrated in a previous paper[1].

3.1 CCD201

This sensor is an e2v standard product. It is used widely for commercial applications, including life science imaging cameras at very low light level. It utilizes the e2v L3Vision or EMCCD technology to achieve sub-electron noise in a 1k X 1k backthinned format sensor. These sensors have also been used for astronomical applications either for high frame rate (with low noise) or for very low signal applications. In particular, it has been evaluated for potential use on the NASA WFIRST coronagraph[6, 7]. Further information is available on the datasheet[2].

3.2 CCD282

This sensor has been developed with the EMCCD architecture for very low noise photon counting and is the largest such device manufactured to date. The sensor has been described previously[8] and is illustrated below.

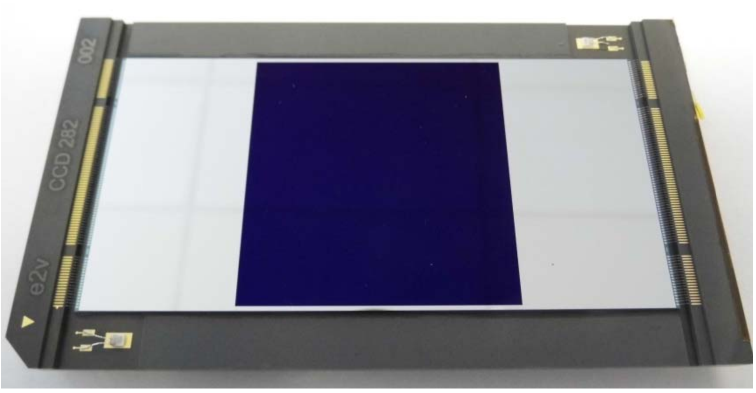

Figure 10. CCD282

The sensor offers a 4K X 4K image format, in frame-transfer architecture with eight outputs for rapid read-out. It is backthinned and optimized for photon counting with very low levels of parallel clock-induced charge; this latter feature can be a performance limitation for such applications. Its development is complete.

3.3 CCD351

This sensor is the latest in the suite of e2v L3Vision commercial sensors, which has recently been developed. It offers backthinned spectral response, very low noise, together with large area and video-rate readout. This sensor is now in production, with datasheet due for publication imminently. See illustration and typical performance below.

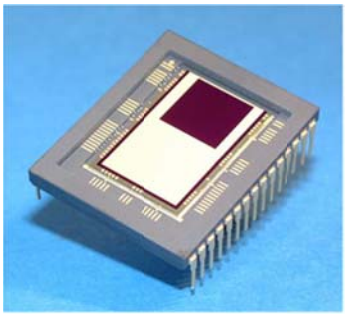

Figure 11. Package illustration of CCD351 (not final version)

Table 5. CCD351 Typical performance

Image section	1024 x 1024
Pixel size	10 µm × 10 µm
Active image area	10.24 × 10.24 mm
Package size	22.86 × 28.00 mm
Amplifier responsivity	3.5 µV/e–
Readout noise	< 1 e- (with EM gain)
Multiplication gain	100-1000 typical
Output data rate	37 MHz
Active pixel charge storage	35 ke-/pixel
Dark signal (18°C)	100 e-/pixel/s

4. PRECISION SYSTEM ASSEMBLIES

e2v continues its development of sub-systems to complement its suite of sensors. Such sub-systems are supplied to custom order and optimized for each application. Here we highlight a few examples.

4.1 WUVS

The WUVS (**W**orld Space Observatory **U**ltra-**V**iolet **S**pectrograph) consists of high-resolution spectrographs to be used on a 2m space telescope. e2v is supplying sensors covering the UV (115-310 nm) range with three channels integrated into custom sealed enclosures together with flight electronics (associated with RAL Space) in a three year programme. The figures below illustrate the custom enclosure concept, and the triple detector system concept.

Key features include: UV optimised sensors, vacuum cryostat detector enclosures, electronic drive modules, interconnect cabling. The CCDs are maintained at -100ºC whilst contributing no more than 3W. Outgassing must be minimal for 9 years of use. The components are designed to withstand shock and vibration of launch and maintain alignment. The instrument is also described in a paper at this conference[10].

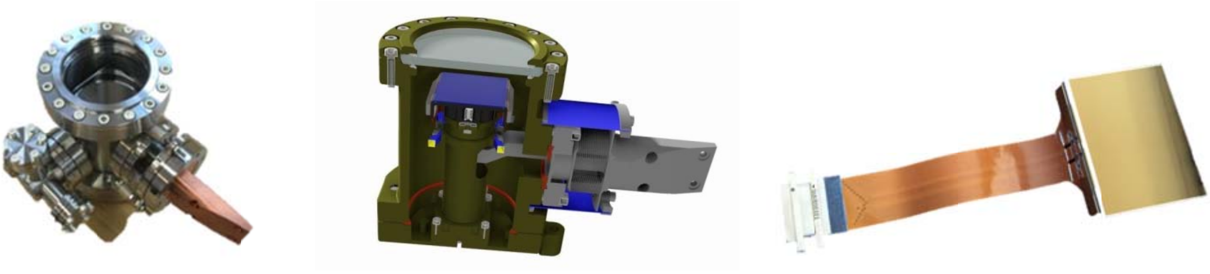

Figure 12. WUVS custom sensor enclosure and CCD272

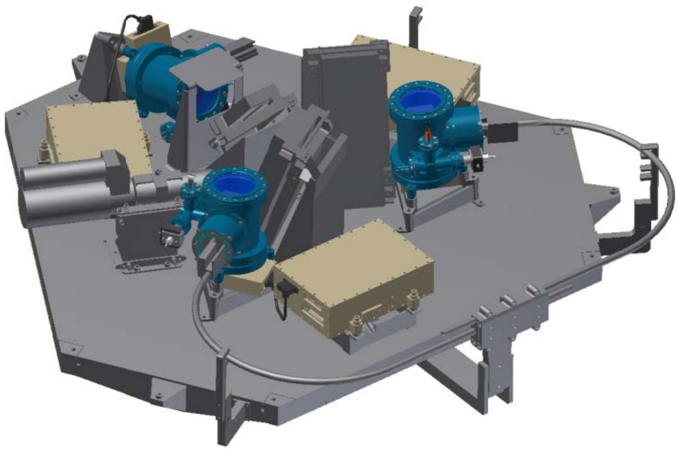

Figure 13. WUVS triple detector layout with camera electronics units

4.2 KMTNet (Ohio)

The Korea micro-lensing telescope network consists of three telescopes each with its own camera for monitoring of micro-lensing events in the galactic bulge. Each camera has four CCD290 sensors to form a 340 megapixel mosaic. e2v has designed, constructed and delivered the three assembled FPAs as illustrated below. The FPAs are integrated into cryogenic cameras built by Ohio State University.

The focal plane flatness is better than 30 µm across the 300 mm diameter. See a previous paper for some further information on the assembly[1] together with a paper at this meeting[11].

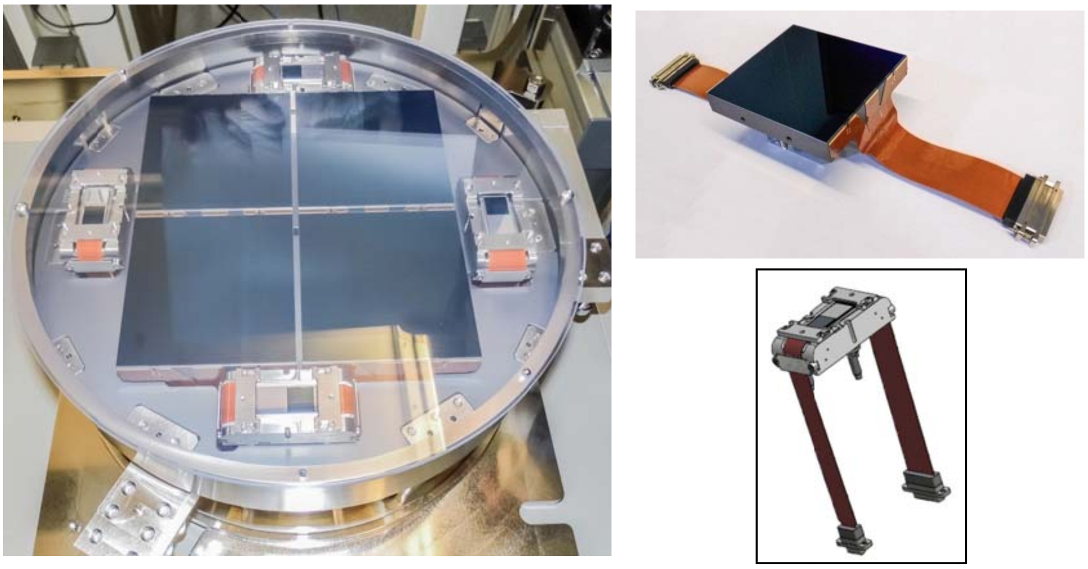

Figure 14. KMTNet focal plane, with CCD290 science sensor and CCD47 guider

4.3 JPAS Cryocam

e2v has just completed the manufacture of a 1.2 Gig pixel cryogenic camera for use on the OAJ telescope operated by CEFCA (Spain). This JPAS camera has been described in outline previously[12] and its performance (after completion) is fully detailed in a paper at this meeting[13].

Key features of the cryogenic camera are presented below together with figures illustrating the camera.

Table 6. Key features of e2v J-PAS cryocam

450 mm focal plane diameter	-100ºC operating temperature	Stable to +/- 0.5ºC
27 µm peak-valley flatness	Measured at -100C	Stable against gravitational flexure
14 science CCD290-99 sensors	1.2 Gig pixels	9K X 9K sensors
8 wavefront sensors	CCD44-82 FT	Custom packages
4 guide sensors	CCD47-20 FT	Custom packages
Integrated electronics	224 science channels	< 5 e- read-noise at 400 kHz
Modular CCD drive units	Synchronized readout of science CCDs	Local frame stores
Complete LN2 cooling system	Integrated vacuum system	Post-delivery support
Cold light baffle	High QE/ minimum reflection AR	


Figure 15. J-PAS Cryocam (a) exploded view (b) photograph of camera

5. SUMMARY

e2v has a significant heritage of supplying high performance backthinned silicon CCD sensors to the space and astronomy community. In recent years an increasing number of CMOS sensors have been developed all with high specifications and multiple features for differing applications. To complement the supply of sensors e2v has supplied various sub-system solutions with customized design and detector-limited high performance. These components form building blocks for future supply of sensors and systems to well defined specifications and a strong in-house supply chain.

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