DEVELOPMENT OF A BACK THINNED CCD FOR THE MEDIUM RESOLUTION IMAGING SPECTROMETER

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ABSTRACT

This paper describes the requirements, main features and performance of a back thinned CCD developed for the European Space Agency as part of the Medium Resolution Imaging Spectrometer (MERIS) programme.

MERIS is a core instrument for the European polar orbiting environmental satellite, ENVISAT I, which is scheduled to be launched in 1998. The instrument will be an imaging spectrometer which will scan Earth surface by a pushbroom method, using CCD arrays to provide spatial sampling in the across-track direction and satellite motion to scan in the along-track direction.

The instrument is designed to allow the spectral and spatial features of the Earth signature to be addressed programmably by both on-chip and off-chip image processing.

The choice of CCD has been based around the EEV CCD05-20 three phase front illuminated device. These have formats of 780 x 1152 elements with 22.5μm pixels and are fabricated using the EEV "stitching" technology.

The CCD development activities have included, full chip thinning, spectral responsivity optimisation for the MERIS mission, flat package development, store shield development, environmental testing and CCD characterisation. Results from the initial characterisation programme will be presented. In addition a customised CCD (CCD25-20, a variant of the CCD05-20), has been designed with dump drain features to aid on-chip image processing,

1 BACKGROUND

The Medium Resolution Imaging Spectrometer (MERIS) is required to measure Earth radiance at a spatial resolution of approximately 250 m or coarser in selected spectral bands in the wavelength range from 400 nm to 1050 nm, at resolutions as fine as 2.5 nm.

The optical system is designed to image a dispersed image of the ground swath onto a CCD such that the CCD lines record the spatial image and the columns record the spectral image. The spatial and spectral image output from the CCD is updated at a frame rate appropriate to the spatial resolution and effective ground velocity of the satellite.

To satisfy the demanding requirements of MERIS a special development activity has been undertaken to tailor the design of a standard CCD for the MERIS application.

2 DISCUSSION OF THE REQUIREMENTS

A discussion of some of the main requirements placed on the MERIS CCDs is presented below. A much more detailed specification was prepared as part of the development programme.

2.1 SPECTRAL RESPONSE

The MERIS instrument is required to provide good radiometric performance out to the extremes of the spectral range 400 to 1050 nm. This is not possible with conventional front illuminated CCDs which typically have close to zero responsivity at 400 and 1050 nm. Furthermore, it is advantageous to tailor the spectral responsivity between 400 and 1050 nm to optimise the system throughput, particularly compensating for the low grating reflectivity in the near infrared.

The chosen approach was to utilise a back illuminated CCD for improved responsivity at 400 nm and a moderately thick silicon layer and quarterwave coating at 1000 nm for improved near infrared performance. A high resistivity silicon was specified to ensure that the MTF was not significantly degraded despite its thickness.

2.2 DEVICE FORMAT

The format of the CCD has been derived by consideration of a number of performance requirements. This includes the sampling requirements in the spectral and spatial domain, the radiometric requirements, both range and resolution, and the field of view limitations of optical systems associated with obtaining well corrected images over the required spectral range. In addition a deliberate decision was taken to base the design as closely as possible on an existing device format to limit the development timescale and risk.

The chosen CCD format has an image area of 780 columns and 576 lines and is based on an EEV CCD05-20 device configured for frame transfer operation.

2.3 ARCHITECTURAL CONSIDERATIONS

Each CCD will cover a spectral range 400 to 1050 nm. The basic user requirement is for 15 spectral bands within this range with nominal bandwidths of 5 to 40 nm. The 15 spectral bands represents approximately 30% of the full spectral image.

The limitations on the CCD pixel storage capacities require the spectral bands to be distributed over multiple CCD pixels to collect sufficient charge to obtain the required signal to noise ratios.

Reading out the whole of the CCD storage region in the required frame period of approximately 40 msec would lead to a data rate of over 10 Mbits/s. This is inconvenient since it would require fast high resolution analogue to digital converters and would lead to high noise and excessive power consumption. To minimise the problem it is found more efficient to undertake some preliminary on-chip processing.

The on-chip processing involves two different techniques. First, summing of CCD lines in the readout shift register to form complete or partial spectral bands. Secondly, dumping unwanted information prior to readout. The two above steps are undertaken multiple times within each frame period.

The two processing techniques are programmable by telecommand and provide selectable spectral bands and selectable spectral resolution in each spectral band. The processing techniques performed on chip reduce the average data rate by a factor of ten.

Fast dumping of the unwanted CCD lines is accomplished by transferring charge across the shift register into a dump drain.

2.4 DEVICE PACKAGING

The MERIS CCDs are required to interface to a spectrometer system which utilises an optical corrector block close to the focal plane and requires a CCD flatness of $\pm 5\ \mu m$. In addition, one side of the CCD butts up to the imaging optics and is further constrained in dimensions. This poses a number of constraints on the device package. To resolve these problems a new CCD package was developed.

3 DEVELOPMENT ACTIVITIES

The MERIS CCD is a frame transfer device of the same basic design and architecture as the EEV CCD 05-20 with 780 by 1152 active pixels (including storage area and dark reference pixels), but with the following modifications:

(i) A design appropriate for back illumination.

(ii) An optimised spectral response.

(iii) A charge dump drain adjacent to the readout register to facilitate a fast clear operation of unwanted image charge.

(iv) A read-out register capacity sufficient to bin up to 4 lines from the image section.

(v) A package design appropriate for access to close proximity optics and a CCD surface flatness of $\pm 5 \mu m$.

To achieve these modifications it was necessary to undertake the following developments:

(i) Extend the "windowing" technique of thinning the CCDs, developed at EEV on the smaller TV format CCDs, to full chip thinning.

(ii) Develop a method of evaporating a well aligned store shield to the unstructured back surface and deposit an anti-reflection coating of optimum thickness.

(iii) Undertake device modifications to increase readout register charge storage, provide parallel charge dumping and enable retention of gate protection on full chip thinned devices.

(iv) Develop a customised flat package.

The above development activities were concluded with a performance assessment of the fabricated devices.

4 DESIGN FEATURES

The main design features of the CCD are listed below:

Parameter	Value
Architecture	Frame transfer Parallel dump register
Format	780 columns x 1152 lines (image + storage)
Pixel size	22.5 x 22.5 μm
Silicon resistivity	100 Ohm.cm $\pm 30\%$
Device thickness	15μm $\pm$ 2μm
Depletion depth	10μm $\pm$3μm
Illuminated mode	Backside
Output amplifier	Single stage buried channel FET
Amp. charge conversion	0.6 $\pm$ 0.1 μV/electron
Anti-static protection	on all gate connections
Saturation limits	
pixels	$>$ 515,000 electrons
output register	$>$ 2,250,00 electrons
output amplifier	$>$ 2,250,00 electrons
Time to clear dump drain (residual charge $< 0.01\%$)	$<$ 100 μs after last transfer
Operational clock rates (max):	
Image region	0.5 MHz
Store region	0.5 MHz
Readout register	3.0 MHz
Image area flatness	$\pm$ 5μm

The new device format with the dump drain is known as the CCD25-20.

5 PERFORMANCE

Back thinned versions of the CCD05-20 devices have been manufactured and tested and the new CCD25-20 format with the dump drain have been wafer processed and DC tested. The latter show good performance and are being characterised as part of a later phase of the programme.

The back thinned CCD05-20 devices were assessed for the following performances:

(i) Dark current vs bias voltage
(ii) Dark current & standard deviation of dark current vs temperature
(iii) Charge conversion
(iv) Potential well capacities

(v) Spectral response
(vi) Response non-uniformity
(vii) Device thickness
(vii) Device Flatness

As part of the development programme additional tests were undertaken on the front illuminated devices since these could be undertaken ahead of the back thinning programme and in some cases provided a useful reference. These additional tests included: amplifier linearity, output impedance, electrode capacitances, waveform features, amplifier noise spectrum, anti-reflection coating refractive index and thickness measurements.

The results of the assessment on the back thinned devices are summarised below:

Parameter	**Value**
Dark signal @ 20°C	0.95 nA/cm² (image area only)
Charge conversion	0.80 ± 0.03 μV/electron
Pixel capacity	554,000 electrons
Quantum Efficiency	50% @ 400 nm 80% @ 820 nm 8% @ 1050 nm
Response non-uniformity	> ± 10% (under review)
Device thickness	14.8 ± 1 μm (variation across CCDs was up to ± 0.5 μm)
Image area flatness	< ± 4 μm

The high response non-uniformity is believed to be caused by non-uniformity in the laser anealing system. Modifications are in hand and are expected to improve the performance.

6 FUTURE DEVELOPMENTS

Further work is being undertaken to evaluate the performance of the CCD25-20 device both in the front and back illuminated versions and in particular the operation of the dump drain. In addition the current package is being modified for -30°C operation and for the inclusion of a window which was not part of the initial design modifications.

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