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PRE-DEVELOPMENT OF THE CCD DETECTOR OF THE FLEX MISSION

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I. INTRODUCTION

The FLEX mission is the 8th Earth Explorer mission selected for flight. It will quantify photosynthetic activity and plant stress by mapping vegetation fluorescence. It will advance our understanding of the functioning of the photosynthetic mechanisms and the actual health and performance of terrestrial vegetation.

The FLEX space segment consists of a single satellite, flying in formation with Sentinel-3, carrying a high-resolution imaging spectrometer. The FLEX instrument will acquire data in the 500– 780 nm spectral range, with a required spectral sampling better than 0.1 nm in the oxygen bands (O2-A:759–769 nm and O2-B: 686–697 nm), 2 nm in the chlorophyll absorption band (600-677 nm) and Photochemical Reflectance Index band (500-600 nm) bands, 1 nm in the red edge (697-740nm) and 0.5-0.7 nm in the rest of the spectral range. The instrument measures spectra with an on-ground spatial resolution of 300×300 m^2 over a swath width of 150 km.

The instrument consists of a common telescope and two Offner spectrometers (Low-Resolution LR and High-Resolution HR) providing elementary sampling of 0.56 nm between 500 and 780 nm and 0.093 nm in the two O2 bands. Binning of spectral samples will provide spectral data at the required resolution. The optical design is documented in [1][2]. Fig. 1 illustrates the optical layout and its implementation.

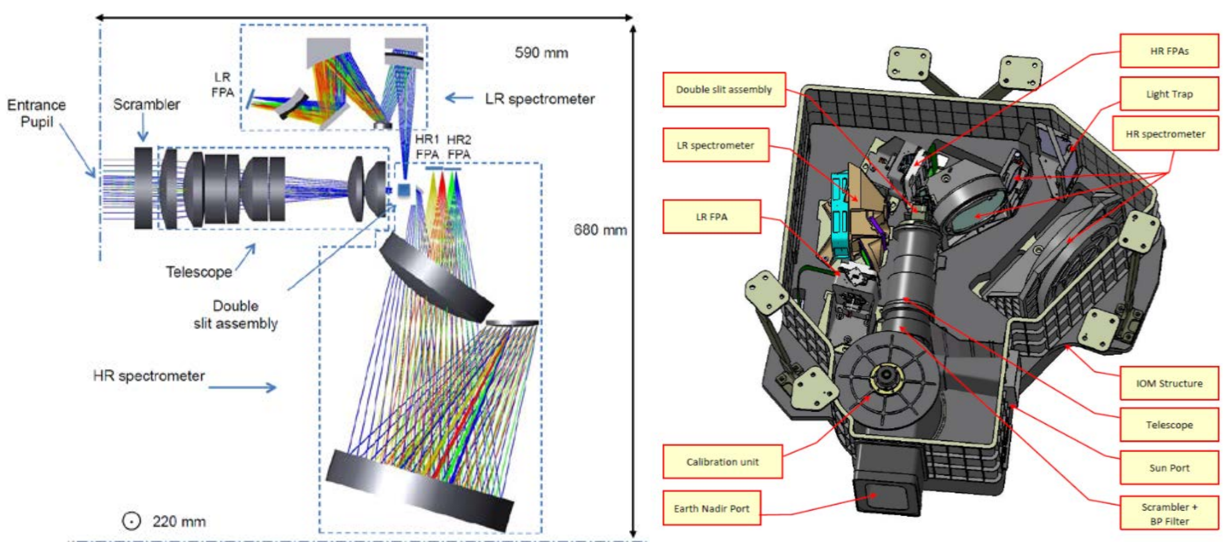

Fig. 1 Conceptual optical layout (left) [1] and CAD view of implementation

It is anticipated that the instrument will feature a mass of 130 kg and 110 W average power and will be flow on a satellite of 500 kg (dry mass) with solar array power of 700 W (End-of-Life, EOL).

Mission development will start in Fall 2016 with phase B2 of the payload. Various pre-developments, including the detector and the optical system [3], were initiated during previous study phases to reduce the risk of instrument development. It is planned to procure the spacecraft and the rest of the elements of the mission at the end of 2017. The earliest launch date is estimated to be end of 2022.

II. FOCAL PLANES

The instrument will feature two focal planes using the same detector. The focal plane of the LR spectrometer uses a single detector completely covering the spectral range between 500 and 780 nm, whereas the HR focal plane uses two detectors located side-by-side to cover the two disjoint O2 bands. Each detector has a useful imaging zone of 450 (spectral) columns by 1060 (spatial) rows with pixels of 28 µm (along rows) x 42 µm (along columns).

After trading off various detection options in the phase A of the FLEX mission, a split frame-transfer CCD was chosen as a best compromise to meet the major requirements, particularly dynamic range, quantum efficiency and linearity (see Table 1) with a limited development risk. Fig. 2 illustrates the general architecture of the CCD (named CCD325) and the assumption made for the configuration of the HR focal plane with its two side-by-side close CCDs.

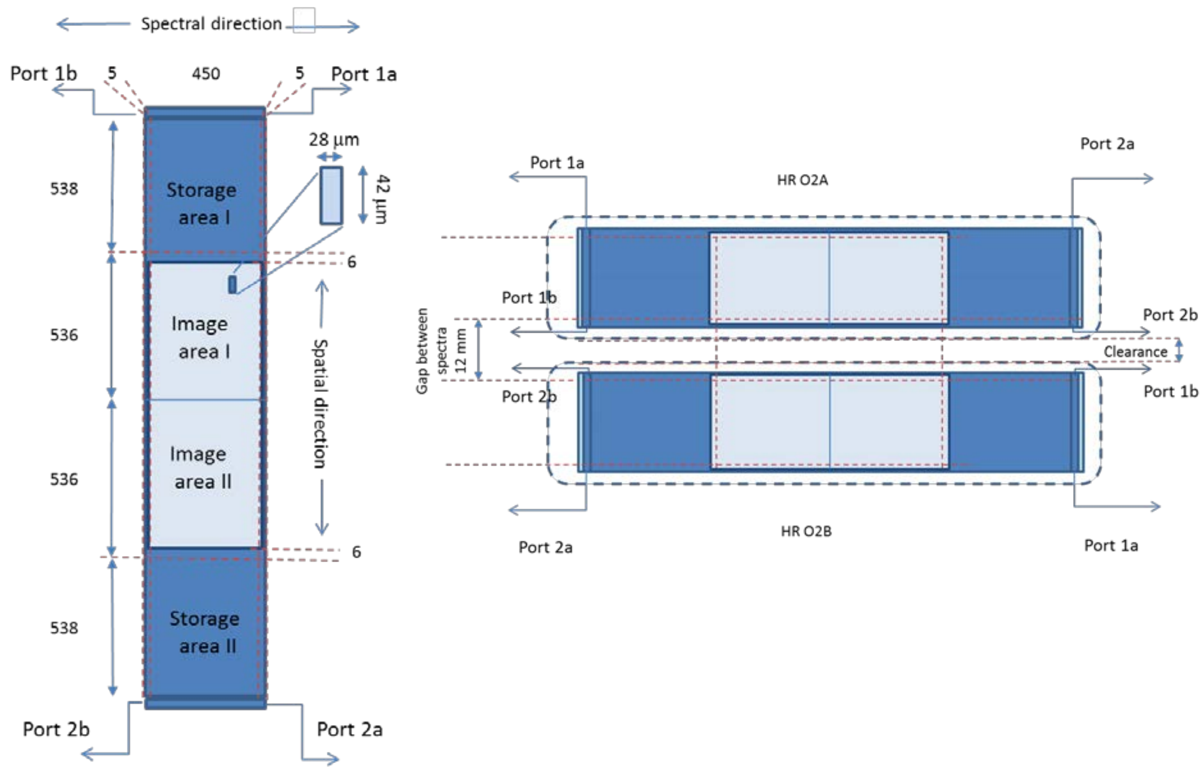

Fig. 2 Layout of the CCD (left) and configuration of the HR focal plane (right)

The size of the useful imaging section, which includes margins for alignment, is extended by masked isolation rows and columns, leading to a full image area of 460 columns x 1072 rows, divided in two independently clocked image zones. Note in Fig. 2 that the mask covering the storage zones extends over the image zones by 6 isolation rows.

Each split image is transferred to a dedicated storage zone from which it is read out via a serial register. Each bidirectional serial register has two output ports with the possibility to functionally split the register and read out each half via the two output amplifiers. The baseline for FLEX is to use one amplifier, which will be chosen according to focal plane accommodation and performance considerations. Two successive rows are binned in the serial register before readout.

III. REQUIREMENTS AND DESIGN OF CCD325

Requirement	Value	Comments
Full Well Capacity (FWC)	1.25 Me-	At elementary image pixel
Charge Handling Capacity	2.5 Me-	At output, after binning of two successive rows
Charge transfer efficiency	>99.999%	EOL
Frame period	45. 44 ms	
Register clock frequency	3 MHz	Output rate
Row transfer frequency	800 kHz	Minimum
Charge to Voltage Conversion (CVF)	0.66 µV/e- +/- 10%	
Nominal operating temperature	253 K	
Quantum efficiency	> 70 % [500 - 780 nm] > 80% [677– 697 nm] > 85% [740-780 nm]	

Read noise	43 e-	Bandwidth: 12 MHz, single-ended operation
Dark current	< 0.07 nA.cm^2	EOL
MTF	> 0.55	
Non-linearity	< 0.01	Relative value, in a dynamic range between 1000 e- and CHC
Fringing	< 1 %	

Table 1 Main requirements of the FLEX CCD detector

Table 1 summarizes the main requirements for CCD325. To achieve FWC and frame transfer speed requirements, a three-phase architecture with metal-buttressed electrodes was selected. This architecture allows fast transfer of each half of the image region to the two store regions at a row transfer rate of at least 800 kHz, to minimise smear signal during transfer from image to store zones. The implementation of the design in blocks ensures fully independent clocking of all image and store regions. The long aspect ratio of the detector and the requirement for close alignment along one long side in the HR spectrometer impose constraints on the positioning of electrode feed buses and of connection pads, which should be located only along the short sides. This is illustrated in Fig. 3 showing the asymmetric layout and one front-side illuminated device.

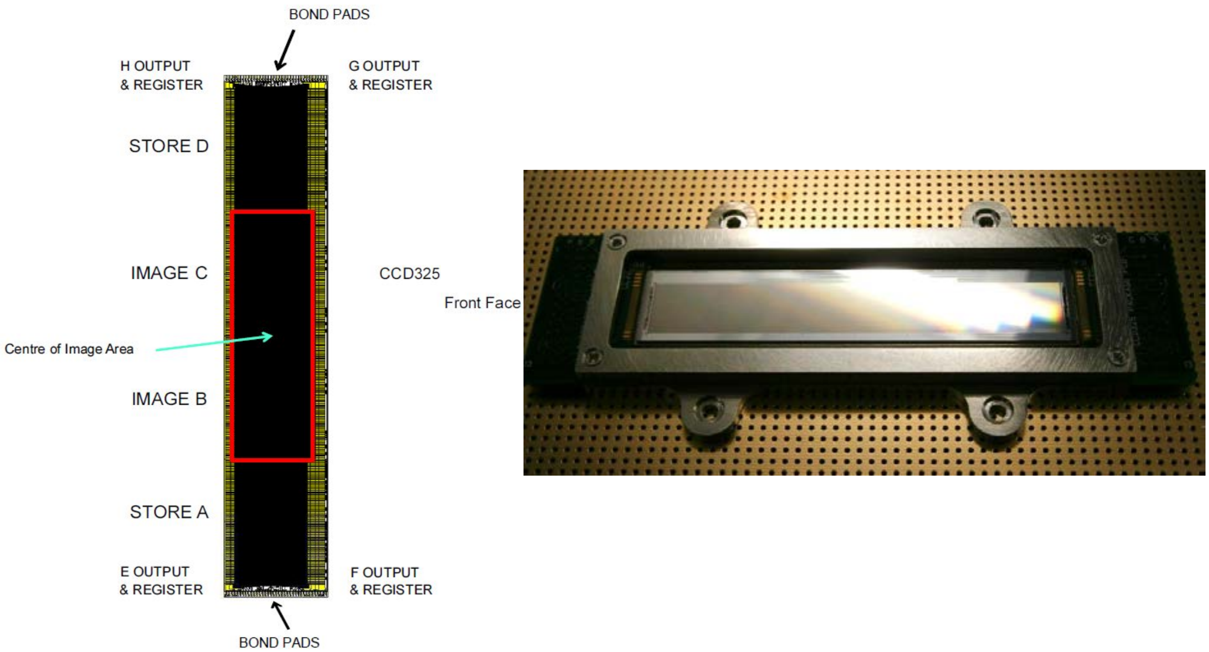

Fig. 3 Left: Layout of the CCD325 showing the asymmetric position of the image area
Right: front-illuminated CCD325 in pre-development PCB package, without window

The 3-phase pixels of 28 x 42 μm^2 are operated in a non-inverted mode (NIMO) and use e2v's "thin gate process" [4], which is advantageous in reducing the flat-band voltage shifts associated with harsh radiation environments. Simulations show that the FWC should at least reach 1.3 Me- with, a nominal expected FWC of 1.55 Me-. Little difference in FWC is expected between static (integration) and dynamic (transfer) conditions. Simulations have shown good transfer performance at the required frequency of 800 kHz and possibility of transfer up to 1.5 MHz with precautions to minimise drive resistance.

Image transfer with high CTE is of high importance for FLEX. It is expected that this design will meet the requirement. However only detailed tests after irradiation will demonstrate CTE performance. Optimization of operation conditions, temperature and transfer frequency might be necessary to achieve compliance with the EOL requirement. Achieving the EOL dark current requirement might require a small decrease of operating temperature. This will be experimentally assessed on irradiated devices.

The four separately clocked register sections are of 3-phase sequence with a channel width of 110μm on a 28μm pitch. This is adequate to receive two pixels at FWC plus a sizeable margin. The electron transport limit is expected to be adequate for at least 3MHz serial read out rate. A gated dump drain is available.

The CCD325 includes four identical low noise output circuits.The output circuits are designed as a conventional two-stage type with a node capacitance C_N ~ 149 fF, corresponding to a CVF at the output of 0.75 μV/e-, taking into account the gain of the output amplifier. This gives a maximum charge handling capacity of ~ 2.8Me- with a 3V signal swing at the sensing node, which is in excess of twice the pixel FWC. Trimming of CVF is possible using an on-chip metal padding capacitor. A simple metal mask change would enable any future adjustment to the CVF. The required read noise should be achieved, given the heritage in similar output stages. Dummy output circuits are available and separately powered for noise subtraction.

Optimum use of data requires correction of smear effects caused by illumination of the device during image transfer. An extended store region is generally implemented, with extra “smear rows” where smear signal generated in the image zone are stored. The charges in the smear lines are usually binned together in the serial register. In CCD325, benefit will be taken of the independent clocking of each section to accumulate smear signal in the first row of the store section. A specific sequencing has to be developed and optimised for smear accumulation in this manner.

The CCD is built with high-resistivity (1500 Ω.cm) silicon and thinned to about 35 μm, to reach the high QE, high MTF and low fringing requirements. An “anti-etalon” patterning of the front-side dielectric surface [4] further reduces fringing. A single AR coating will be used for this pre-development, although the use of different AR coatings, optimised for each band, can be considered for the flight devices.

IV. STATUS OF DEVELOPMENT

Silicon wafers implementing this design have been processed, with a part of the lot used to build prototype non-thinned devices and the rest of the lot being sent to thinning and back-side processing. The non-thinned devices are used for optimisation of operating conditions and initial design-proving in a front-illuminated configuration; one of these devices is shown below in Fig. 3. Tests will cover imaging functionality, defects, dark signal, CVF, CTE, FWC, linearity and amplifier noise. Preliminary results show nominal functionality of the devices.

A full electro-optical test programme will be carried out on thinned back-illuminated devices to ascertain their performance for FLEX. A similar test programme will be applied to other devices subjected to gamma irradiation (at 2.5, 5, 7.5 and 10 krads) and proton irradiation (fluences: $5x10^8$, $1x10^9$ and $5x10^9$ protons/cm^2 at a proton energy of 10 MeV). For proton testing, devices will be shielded to achieve the required doses and provide a control region. Proton-irradiated devices will be tested for Random-Telegraphic-Signal (RTS) effects.

It is expected that the work will be completed in the Fall of 2017.

CONCLUSION

The pre-development of the CCD detector was initiated in 2014 to reduce risk of the FLEX mission development. This enables careful concept trade-off, design and systematic manufacturing and test of the detector, to bring its definition to a level allowing the start of larger investments for the instrument. First prototypes are available at the start of phase B2, with a work programme ensuring availability of full characterization data, including in conditions simulating EOL conditions by the end of phase B.

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