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COMPLEX PIXELATED OPTICAL FILTERS

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I. INTRODUCTION

Multispectral or hyperspectral images allow acquiring new information that could not be acquired using colored images and, for example, identifying chemical species on an observed scene using specific highly selective filters. Those images are commonly used in numerous fields, e.g. in agriculture or homeland security and are of prime interest for imaging systems for onboard scientific applications (e.g. for planetology). Those instruments are generally composed with a computer controlled rotating filter wheel placed right in front of a CCD camera [1] (Figure 1). This technology allows integrating on a single camera a large number of filters and therefore to acquire images at a very specific wavelengths or within a well-defined spectral range.



Fig. 1. Example of a set of optical interference filters fixed on a filter wheel and dedicated to the GOCI instrument installed on the COMS satellite [1]

Those filters are generally optical interference filters. Therefore, a large range of optical functions can be achieved for these filters. Another advantage of thin film filters compared to colored organic materials is that they are compatible with space applications. However, it is obvious that these rotating filter wheels are a bulky and heavy solution for hyperspectral imaging that make them non optimal solution for onboard applications while CCD cameras are lighter and lighter.

To overcome this problem, a solution is the fabrication of pixelated filters, similar to the one used for color cameras but using optical interference filters. This way, no filter wheels would be required and filter size would become negligible compared to camera size. In this paper, we present all the steps towards fabricating this new class of filters.

II. PIXELATED FILTERS

A. Spectral Specifications

Pixelated filters can be composed through a MacroPixel with any number of filters, e.g. 2×2, 3×3 or 4×4 with a Bayer-type structure. Each filter is a bandpass filter centered at a specific wavelength with the following specifications:

- Central wavelength between 400 and 1100 nm
- Spectral bandwidth between 10 and 50 nm
- Maximum transmission at resonance exceeding 80 %
- Squared profile in the bandpass is required
- Integrated transmission lower than 10^{-2} out of the pass band

B. Geometrical specifications

Pixelated filters should be massively structured with the following specifications:

- 100 000 to 200 000 MacroPixels should be fabricated in parallel
- Pixel size between 7×7 and $50 \times 50 \mu\text{m}^2$
- Thick multilayer stacks for each filter with typical thickness from 10 up to 15 μm
- Basic pattern will include 4 to 16 different filter's types
- Each filter will be complex as it will require up to 100-150 layers

C. Fabrication method

Structure of the pixelated filter is obtained by deposition through a mask made with a photoresist and using a lift-off technique. Typical procedure for obtaining such a filter is shown in Figure 2.

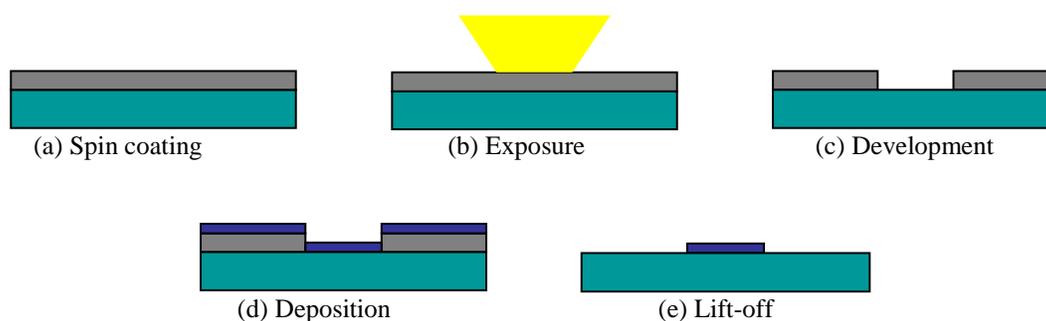


Fig. 2. Description of the lift-off process

The lift-off technique consists in 5 different steps:

- 1 - Spin coating is used to deposit a photoresist on top of a glass substrate (**Error! Reference source not found.a**).
- 2 - Structured illumination is performed through an amplitude mask (b).
- 3 - Photoresist is then developed in order to remove it where exposure was performed (c).
- 4 - Optical interference filter is then deposited on top of this substrate (d).
- 5 - Lift-off of the photoresist is performed in order to remove the coating all over the substrate, in the parts where photoresist was not present (e).

However, as can be seen in Figure 3, the use of simple lift-off technique does not allow achieving flat and squared pixel profile because walls are created on the pixel side due to deposition of a larger amount of material at the boundary with the photoresist.

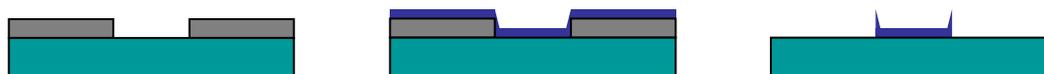


Fig. 3. Illustration of the problem of walls with standard lift-off process

This problem can be solved by using two photoresists having different physical properties and the generation of small caps that will prevent the creation of walls on the edges of the photoresist and therefore obtaining perfectly parallelepipedic pixels (Figure 4).

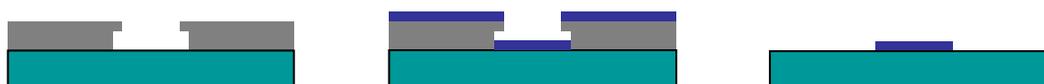


Fig. 4. Two-photoresists-based lift-off process

D. Experimental demonstration

Lift-off technique was used to demonstrate the fabrication of 2 adjacent pixels of a 2×2 pattern. Pixels are bandpass filters with different central wavelength. Typical specifications for this prototype are the following:

- 10 000 MacroPixels
- Pixel size is 30×30 μm^2
- Thickness of each filter is < 4.5 μm
- The 4 bandpass filters have central wavelength 550, 700, 770, 840 nm. 700 and 770 nm bandpass filters are demonstrated here.
- FWHM is ~ 40 nm
- Rejection is performed in 500 – 900 nm range
- Number of deposited layers is ~ 45

Figure 5 shows pictures of two adjacent filters measured using a Zygo NewView 7300 optical profilometer. It is seen that each pixel has a well-defined squared shape with sharp edges. The transition zone is within 2 μm , i.e. below than 10% of the pixel size. There is no overlap between the filters and each pixel displays a flat top which means that uniform properties are expected over the pixel aperture.

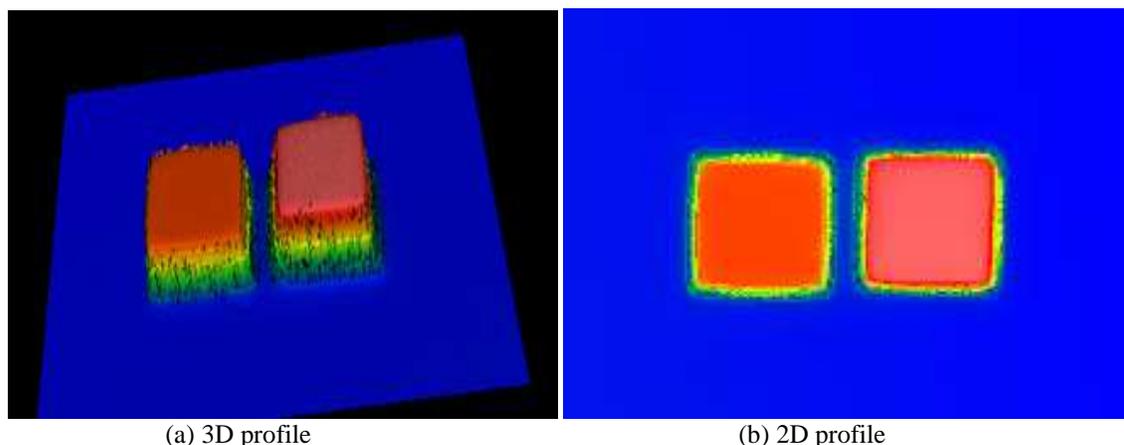


Fig. 5. Spatial profiles of two adjacent 30×30 μm^2 filters measured using a Zygo NewView 7300 optical profilometer

III. LOCAL CHARACTERIZATION OF THE SPECTRAL PROPERTIES OF PIXELATED FILTERS

A. Description of the measurement system

Each fabricated pixel is in the range of 50 to 2500 μm^2 , therefore, local spectral properties cannot be easily characterized with regular spectro-photometric techniques for which the minimum aperture of the measurement is generally within 1 mm^2 . A custom setup was developed within the Institut Fresnel about 10 years ago to allow mapping of the spectral properties of filters over their aperture [2]. This setup is compatible with measurement of the spectral properties of one pixel, but only gives access to the integrated properties of the grating over the pixel aperture. Therefore, it is of prime interest to be able to carry out mappings of the local spectral properties of one pixel with micron lateral resolution and a nanometer (or better) spectral resolution. To achieve a custom optical setup (SPHERE) was developed [3]. This system uses a white light source associated with a double monochromator (Gemini-180 from HORIBA Jobin Yvon) in order to generate a spectrally tunable light source. This source is then imaged in the pixelated filter plane using plane apochromats with a normal incidence and an F-number of 10. A detector placed just before the sample measures the incident power and therefore corrects for its temporal fluctuations. Finally, the pixelated filter is imaged in the plane of a CCD camera (Figure 6).

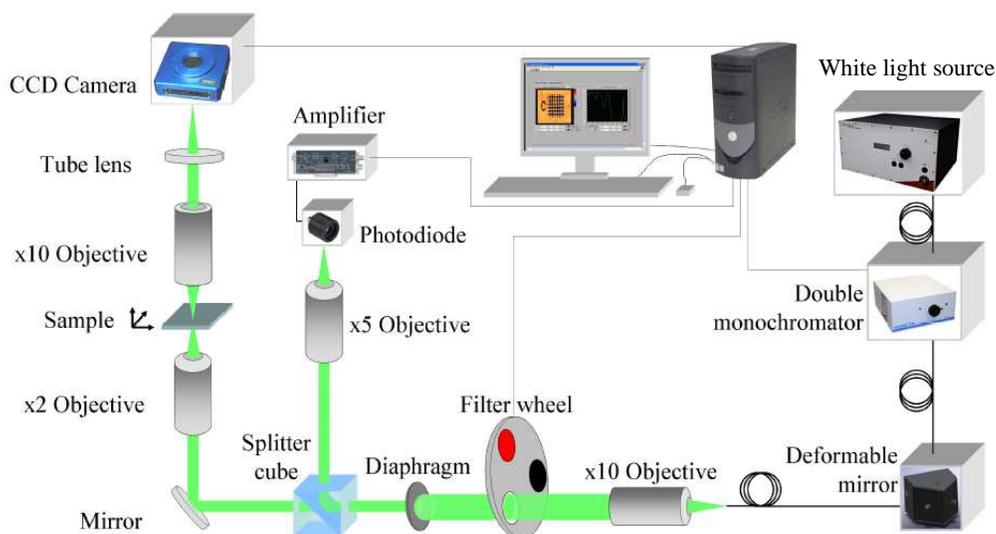


Fig. 6. Scheme of the SPHERE measurement setup

The use of a multimode fiber and a narrowband light source induces, in the measurement plane, an inhomogeneous intensity distribution and speckle. To overcome this problem, deformable mirror and a $200 \times 200 \mu\text{m}^2$ multimode squared core fiber were inserted right after the monochromator in order to achieve uniform exposure at any point along the beam path (Figure 7).

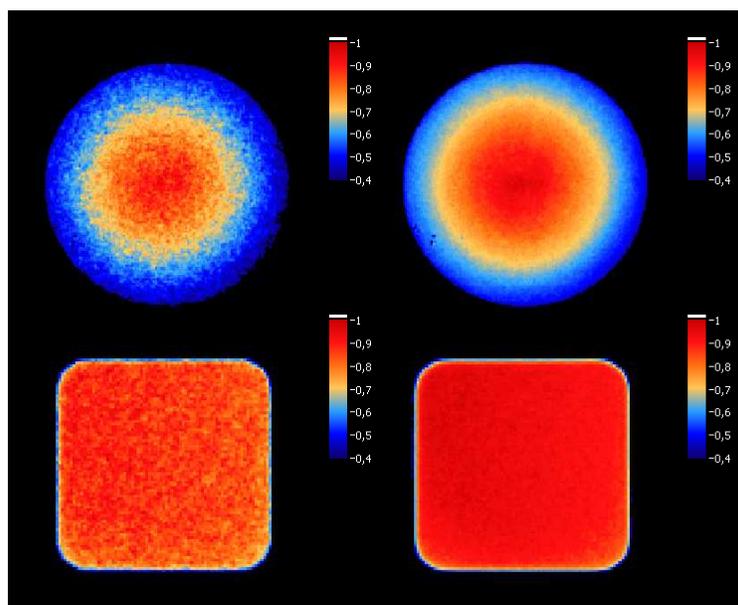


Fig. 7. Intensity distribution on the CCD camera at 600 nm. First line was obtained with a circular core fiber while the second line was obtained with a squared core fiber. Left column was obtained without deformable mirror while the right column was obtained with a deformable mirror.

Using this system, it is therefore possible to perform mapping of the local spectral dependence of pixelated filters with a spectral resolution of 0.5 nm and a spatial resolution of $2 \mu\text{m}$ (resolution on camera is $0.5 \mu\text{m}$, but actual resolution is 4 times higher due to diffraction).

B. Characterization of prototypes

Using the SPHERE setup, the prototype presented in Figure 5 was characterized. Figure 8 shows a mapping of the transmitted intensity over the pixelated surface at 400 nm. One can see a periodic structure with bright transmitting pixels, dark reflecting pixels and some lines without pixels (those one will be deposited in a future run). It is clear that each pixel that had nominally the same deposited structure show identical performances.

Also, it is interesting to note that since wavelength can be scanned from 400 up to 1000 nm, it is possible to obtain the same picture for each wavelength and therefore locally characterize the spectral performances of the filter.

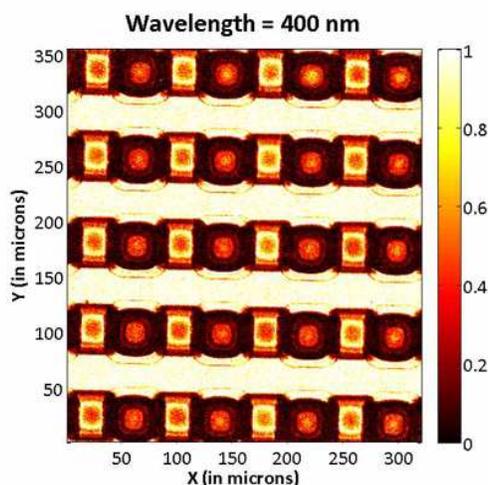


Fig. 8. Mapping of the transmitted intensity of the pixelated filters at 400 nm

To illustrate the spectral performances of one of the pixelated filter, Figure 9 shows the transmitted intensity at 985 nm over one B2 pixel surface as well as the spectral transmission curve of the filter averaged over 5×5 pixels. It is seen that the filter presents a broad rejection band from 500 up to 900 nm (except for a narrow line around 870 nm) and a narrowband resonance around 700 nm.

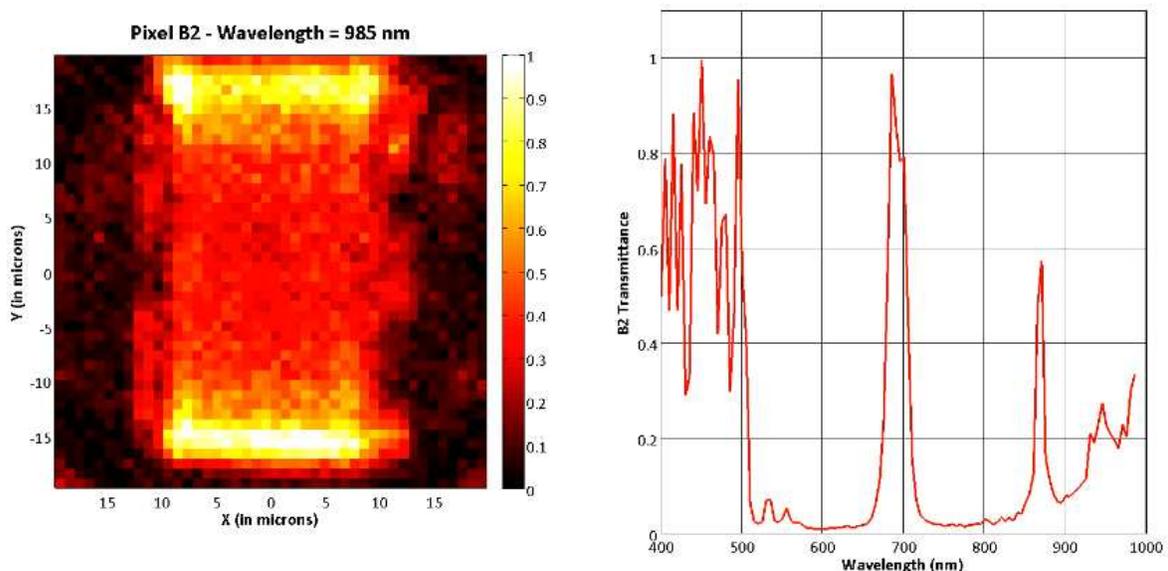


Fig. 9. Mapping of the transmitted intensity over one B2 filter centered at 700 nm

To simultaneously evaluate the performances of the measurement system and the pixelated filter, the spectral performances measured on the pixelated filter (Figure 9) were compared with the spectral transmission measured on the witness sample (25 mm diameter) with a Perkin-Elmer Lambda 1050 spectrophotometer (Figure 10).

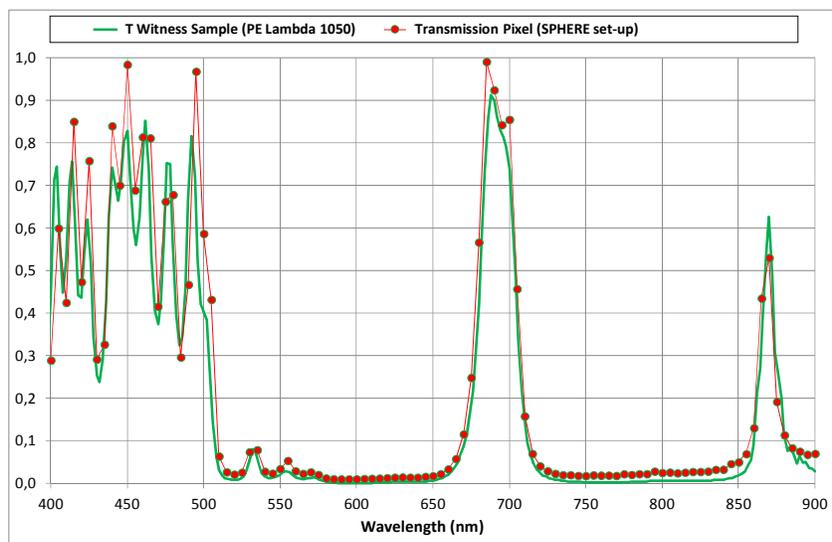


Fig. 10. Comparison of the spectral transmission of the pixelated filter measured with the SPHERE setup and of the witness sample (25 mm diameter) measured with a Perkin-Elmer Lambda 1050 spectrophotometer.

Figure 10 shows that very similar performances were measured on the pixelated filter and the witness sample, confirming that both manufacturing and characterization techniques of pixelated filter allow obtaining high performances' filters.

IV. CONCLUSIONS AND PERSPECTIVES

Fabrication and characterization of pixelated filters have been demonstrated. Dual photoresist lift-off technique associated with Ion Assisted Deposition technique were used to achieve both high spatial and spectral performances. Finally, local characterization of the spectral transmission of pixelated filter was achieved by developing a dedicated custom setup that allows carrying out mapping of this transmittance with a spatial resolution of 2 μm , spectral resolution of 0.5 nm and good signal to noise ratio. A first prototype with 2 elementary pixels was fabricated and characterized.

REFERENCES

- [1] H el ene Krol, Fr ed eric Chazallet, Julien Archer, Laurent Kirchgessner, Didier Torricini, Catherine Gr ezes-Besset. "Narrowband filters for Ocean Colour Imager," ICSO - 7th International Conference on Space Optics - 2008
- [2] L. Abel-Tiberini, F. Lemarquais and M. Lequime, "Dedicated spectrophotometer for localized transmittance and reflectance measurements," *Appl. Opt.*, **45**, 1386-1391 (2006)
- [3] S. Sorce, L. Abel-Tiberini, and M. Lequime, "Spectrophotometric bench dedicated to the characterization of micro-patterned optical coatings," *Proc. SPIE Col.* 8169, 81690N-1 (2011)