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Manufacturing of monolithic and butcher block filter arrays for earth observation applications

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ABSTRACT

Multispectral earth observation is done using selected discrete filter channels. The optical filtering is typically accomplished using optical thin film filters. These filters can be placed in filter wheels or as an array directly in front of the detector. For compact system designs filter arrays are preferred. The manufacturing of filter arrays can be done by two different approaches called monolithic array and butcher block. Typical optical requirements for such filters are for example a filter transmission of above 90% and an out-of-band blocking in OD6 range.

Keywords: coating, PARMS, IAD, VIS, NIR, MWIR, LWIR, lithography, butcher block, evaporation, sputtering

1. INTRODUCTION

For a monolithic filter array, all filter stripes are placed on one substrate next to each other by using a sequence of sophisticated photolithographic and coating processes. Separation of different filter channels is done using a black mask. Filter dimension defined by lithographic accuracy can range from mm to some 10 µm. For filter application ion assisted deposition technologies are necessary. Typically, ion assisted deposition (IAD) is used for the patterning process. With increasing demands on image resolution and signal to noise ratio filter requirements are becoming more stringent. To overcome this, filter coatings by plasma assisted magnetron sputtering (PARMS) technology are preferred. The alternating coating and patterning processes lead to a complex manufacturing flow limiting the number of filter channels to about six.

To overcome this, filter arrays can be manufactured as so-called butcher block. Here, filter coatings are applied on wafer level without any restrictions of the patterning process. Afterwards, the coated wafer is diced in single stripes. The single stripes are then attached to each other with opaque glue building the filter array. On top of the array an additional black mask can be applied. The width of each filter stripe can be from mm range down to 25 µm. A butcher block can be built with two sticks and up to 150 (or more) sticks. Beside sticks, the filters can also be arranged as checkerboard. Assemblies with sticks with different substrate materials and different substrate thickness are also possible.

A third possibility for manufacturing of filter arrays is the integration of single filter stripes into a mechanical frame. This requires beside the manufacturing of filter stripes also the development and manufacturing of a sophisticated mechanical frame. This approach was used for Sentinel 2 MSI [1,2] but will not be further discussed in this paper.

In this paper, we present monolithic filter arrays with filter coatings by PARMS technology showing high transmittance and broadband blocking performance. Furthermore, possible configurations of butcher block arrays are presented.

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2. MONOLITHIC FILTER ARRAYS

Manufacturing of monolithic filter arrays is based on a combination of thin film coating technologies and patterning by means of photolithography. Coating and patterning technologies are described in detail in the following sections.

2.1 Manufacturing approach

The manufacturing of is done by a subsequent cycle of patterning and thin film deposition steps. Typically, the manufacturing is done on wafer level and the filter arrays are diced to their final geometry. The process is carried out under clean room conditions.

For space applications, the wafers are made of radiation hard optical glass such as fused silica or BK7G18. Their size can range from 4 inch up to 8 inch diameter. Also, the manufacturing on CMOS wafers is possible. The patterning starts with the spin coating of a photo sensitive polymer (photoresist) onto the whole wafer surface. A dedicated mask with a defined pattern is then placed over the wafer during illumination with intense UV light in a mask aligner. Areas exposed to the UV light can then be removed in a developer solution leading to a resist pattern on the wafer surface. The thin film coating is then applied on the whole wafer surface. In the following lift off process the photoresist is removed from the wafer surface and the coating only remains on the wafer in areas being not covered with resist. When repeating this sequence several times, it is possible to deposit a thin film coating on dedicated positions of the wafer defining the final filter array. Number of patterning steps depends on the number of different coatings needed for black mask definition and number of filter channels. The minimum feature size for this approach is in the range of 20 µm – 50 µm depending on coating properties. A sketch of the manufacturing flow is shown in figure 1.

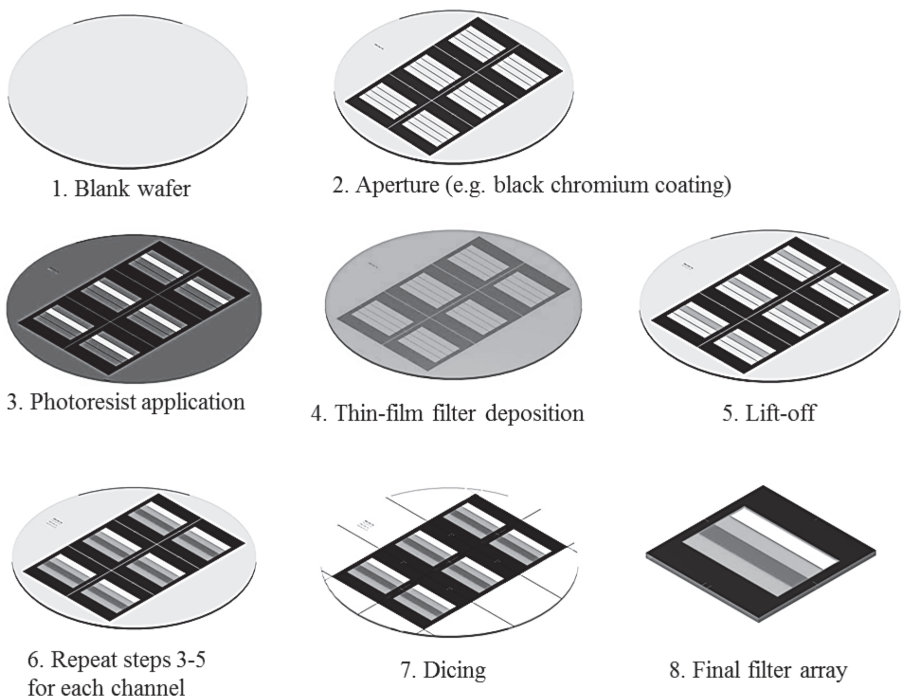

Figure 2 Manufacturing sequence for monolithic patterned filter arrays; from [3].

2.2 Filter arrays with coatings by IAD technology

Traditionally, patterned coatings are manufactured by means of ion assisted deposition (IAD) technology due to parameters such as process temperature and interaction of plasma with the photopolymer. A detailed description can be found in [3]. For the deposition of complex coatings to meet stringent spectral requirements coating chambers are equipped with a broad band optical monitoring system [4]. A good process control is essential for sequential coating steps.
The types of filter arrays manufactured with IAD coatings can range from order sorting filters with coating dimensions in the mm range [5] to seven band filters with a stripe width of 100 µm only [6]. Smallest filter dimension manufactured for space applications is an 1024 x 1024 pixel array with four different color bands and a filter size of 18 µm x 18 µm each. For this, radiation hardness was proofed [7].

2.3 Filter arrays with coatings by PARMS technology

With increasing demands on image resolution and signal to noise ratio of multispectral instruments, requirements for spectral performance of optical coatings become more and more stringent. Especially in-band transmittance and out-of-band blocking are requested. For complex coatings by IAD technology the in-band transmittance for narrow band pass filters (FWHM of 20 nm) is limited to about 85% [8]. This is caused by the intrinsic coating roughness of IAD layers. To overcome this, the high-energy deposition technology of plasma-assisted-reactive-magnetron-sputtering (PARMS) [9] is used. This technology allows the manufacturing of complex coatings with low roughness and low scattering resulting in increased in-band transmittance well above 90% and a possible lower out-of-band signal in OD6 range [10]. To implement the PARMS coating into the lithographic patterning process an adaption of the process was necessary to account for the different process conditions compared to the IAD process [11]. With this accomplished, the manufacturing of monolithic filter arrays with sophisticated spectral performance is possible.

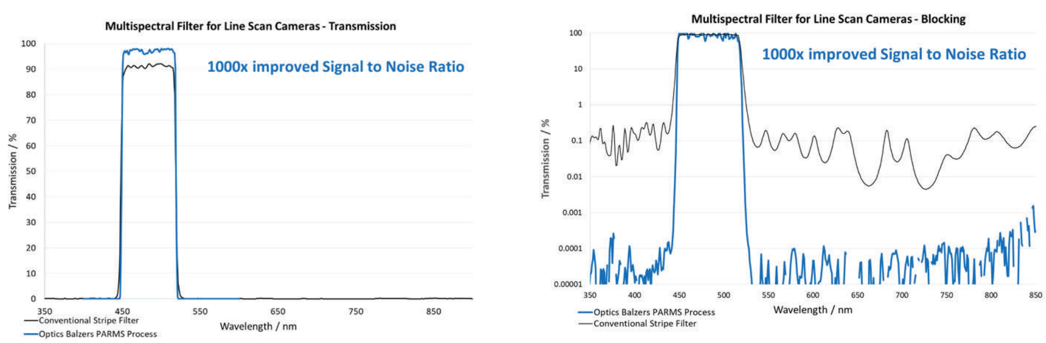

Figure 2. Spectral measurement of in-band (left) and out-of-band (right) spectral performance of a monolithic filter arry with coatings by PARMS technology (blue) compared to IAD technology (black).

Figure 2 shows the comparison of achievable performance of the same filter channel coated by IAD and PARMS technology. A significant increase of in-band transmittance as well as out-of-band performance can be found.

Both approaches are eligible for use in space environment.

3. BUTCHER BLOCK ARRAYS

A second possibility of filter array manufacturing is the butcher block concept. Here, the coatings can be applied without restrictions of the lithography process. Manufacturing approach and examples are described in the following.

3.1 Manufacturing approach

For a butcher block, the coating deposition has all degrees of freedom. Normally, coatings are applied on wafer or plate level for each spectral band needed. After coating deposition, the wafers are diced into sticks with the desired width and not necessarily final length. Filter width can range from mm range down to 25 µm. The sticks are now assembled with an opaque glue between the individual sticks. This thickness is typically 15um an offers OD5 blocking. Number of assembled sticks can range from 2 to 150; or more if required. On top of the assembly, it is possible to apply a black mask for channel separation. In a final step the assembly is cut to its final size.

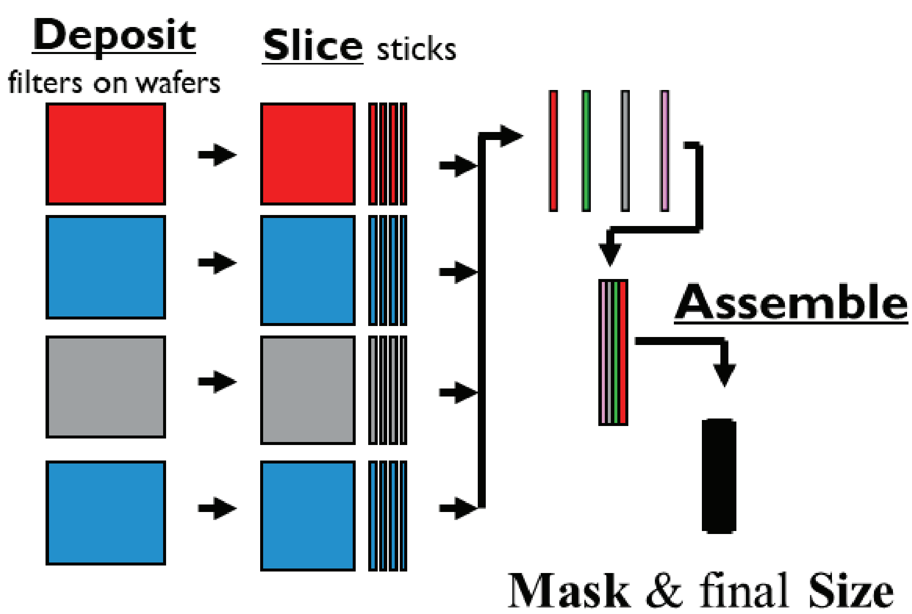

Figure 3. Sketch of the manufacturing approach for butcher block filter arrays.

The assembly is also possible for rectangles in a checkerboard pattern, for different substrate materials, and for different thickness of the individual parts. Manufactured examples are shown in figure 4.

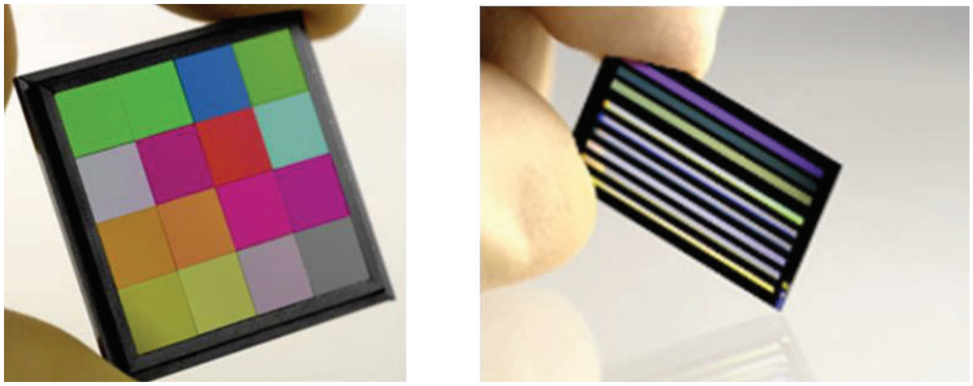

Figure 4. Images of manufactured butcher block arrays with checkerboard pattern (left) and filter stripes (right).

3.2 Butcher block filter arrays

For deposition of coatings for a butcher block assembly no constraints exist comparable to the monolithic arrays due to the lithography process involved. All types of coatings techniques can be used for filter deposition no limit of filter thickness exists. It is even possible to manufacture arrays with filter channels covering UV, VIS, NIR, SWIR, MWIR, and LWIR spectral ranges.

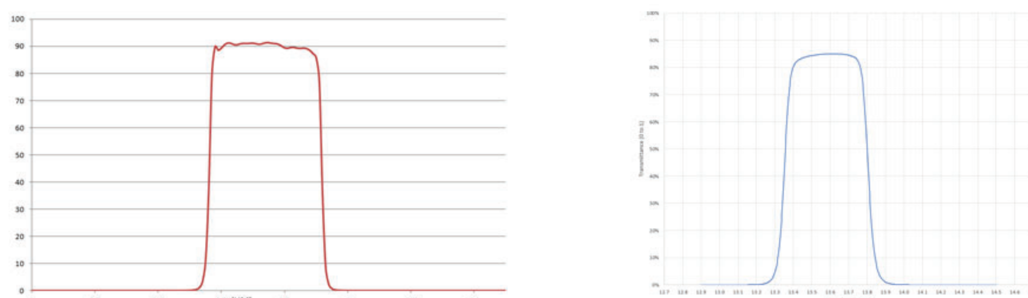

Figure 5. Exemplarily curves of band pass filters in infrared spectral range.

Due to the variability of the butcher block process, it is possible to manufacture arrays for use in hyperspectral applications. A manufactured example can be seen in figure 6.

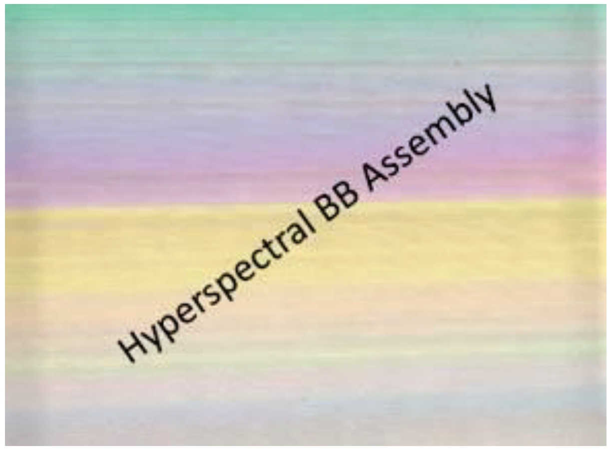

Figure 6. Image of a manufactured hyperspectral butcher block filter array.

4. CONCLUSION

In this paper, Materion Balzers Optics (MBO) shows capabilities of manufacturing of filter arrays. Different approaches are presented to cover a broad range of applications concerning geometrical feature size and also spectral ranges. In addition, the advantages of the PARMS coating process compared to the IAD process is discussed.

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