Design and Fabrication of a patterned dual colour filter using Microwave plasma assisted Sputtering and Photolithography

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Abstract: A patterned dual colour filter has been deposited by low temperature microwave plasma assisted pulsed DC sputtering (MPAS) and photolithography. Compatibility between MPAS process and photolithography for fabrication of patterned optical filters has been demonstrated.

1. Summary

Multispectral imaging captures image data in different wavelength ranges across the spectrum and is increasingly used across a diverse range of industries [1]. Wavelength separation is required and is best achieved through the use of multiple filters based on thin film optical interference coatings. Microfabrication of these filter arrays reduces size and removes the need for a difficult and labor intensive dicing and gluing process [2].

Microwave plasma-assisted pulsed reactive DC magnetron sputtering (MPAS) has previously been demonstrated to be a robust, high throughput, repeatable and low temperature process for thin film deposition [3, 4]. It can be used across a wide range of wavelengths from visible to mid-wave infrared [5, 6]. Due to the low temperature of deposition it has also been shown to be compatible with deposition directly onto detector surfaces[7]. This current work demonstrates compatibility of the MPAS process with conventional photolithography and the successful design and fabrication of a dual-color optical filter. Filter was fabricated through combining the MPAS thin film deposition with a photolithography lift off process.

1.1. Microwave plasma-assisted magnetron sputtering (MPAS)

Thin film multilayer optical coatings were prepared using a novel MPAS reactive pulsed DC magnetron sputtering technique. The system used is shown in Figure 1. The apparatus was equipped with a complete microwave generator system comprising a 6 kW microwave magnetron head, tuner, and microwave delivery tubes. In this work, thin films of Tantalum pentoxide (Ta_2O_5) and silicon dioxide (SiO_2) were obtained by sputtering from tantalum (Ta) and silicon (Si) bulk sputtering targets, each with 99.999% (5 N) purity.

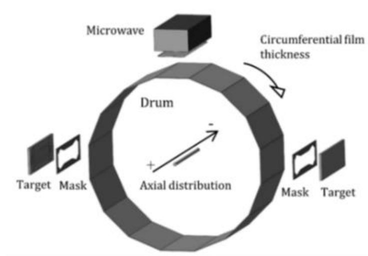

Fig. 1. Schematic of the microwave plasma-assisted sputter reactor used to deposit the optical thin films described in this work

The deposition rate and thickness of the film were monitored in real-time by quartz crystal thin film thickness monitors (Inficon IC5, Inficon Inc., Bad Ragaz, Switzerland). Argon is used as a sputter process gas, and oxygen as a reactive gas. The flow rate of gas was accurately controlled by a MKS mass flow controllers (MKS Instruments Inc.,Andover, MA, USA). The chamber body was heated by hot water to liberate any residual H2O molecules on the chamber walls, thereby increasing their probability of being trapped by Meissner cooling coils (Telemark polycold model 3600, Telemark Inc, Battleground, WA, USA).

Table 1. The deposition parameters used to grow thin films of Ta2O5 and SiO2. Both materials were run in power control mode.

Material	Ar Flow ($sccm^{-1}$)	O2 Flow ($sccm^{-1}$)	Power (kW)	Current (A)	Voltage (V)	Microwave Power (kW)	Pulsed DC Frequency (kHz)	Deposition rate (nms-1)
SiO2	190	40	3.6	9.0	400	2.75	46	0.1
Ta2O5	190	90	3.5	11.7	300	2.20	46	0.095

1.2. *Photolithography*

The optical films were deposited in two photolithography steps with lift-off photoresist used. The lift-off resist is applied in two layers: The bottom layer (release layer) is Polydimethylglutarimide (PMGI -SF11) manufactured by MicroChem, 1254 Chestnut Street, Newton, MA 02464, USA. The top layer (imagining layer) is Microposit S1813 manufactured by Shipley Company, 455 Forest Street, Marlborough, MA01752, USA. The exposure system used a Karl Suss MJB3 mask aligner with a UV source of 436nm. The S1813 resist was fully developed in MF319 developer leaving the underlying PMGI exposed. The PMGI was flood exposed using DUV of 193nm and the development was completed with MicroChem 101 developer.

1.3. *Optical Characterisation & Design*

Optical transmittance measurements were carried out using a Perkin-Elmer lambda 40 spectrophotometer. For refractive index determination samples were deposited on JGS3 substrates and fitted employing a multiple Kim's oscillation model[8]. For SiO_2 films a thin layer of Ta_2O_5 was deposited prior to SiO_2 due to the similar index of SiO_2 and JGS3. Optical filters were designed using filmstar DESIGN thin film design software.

2 filters were chosen for deposition; a longwave pass visible yellow filter and a notch magenta filter, both to operate in transmission. Thickness of filter layers are given in table 2. This were deposited in a checkerboard pattern of squares with sizes of 10mm, 5mm, 1mm & 500µm on 3" diameter 0.5mm thick Fused Silica.

Table 2. Design thicknesses of the 2 filters

Layer Number	Material	Magenta Filter Thickness (nm)	Yellow Filter Thickness (nm)
1	Ta_2O_5	63.5	43.3
2	SiO_2	89.4	64.7
3	Ta_2O_5	64.2	49.9
4	SiO_2	86	74.2
5	Ta_2O_5	60.9	49.9
6	SiO_2	91	74.2
7	Ta_2O_5	60.9	49.9
8	SiO_2	91.5	74.2
9	Ta_2O_5	61	49.9
10	SiO_2	90.3	74.2
11	Ta_2O_5	61.5	49.9
12	SiO_2	87.7	66.1
13	Ta_2O_5	63.2	48.1
14	SiO_2	183	143.7

2. Results

2.1. *Optical Performance*

Patterned sizes and 10mm, 5mm, 1mm and 500µm. Optical performance of each filter was measured in transmission on JGS3 substrate witness pieces included in the 2 deposition runs. Measured transmission is shown in figure 2 compared to modelled design performance. Both results show good agreement with design.

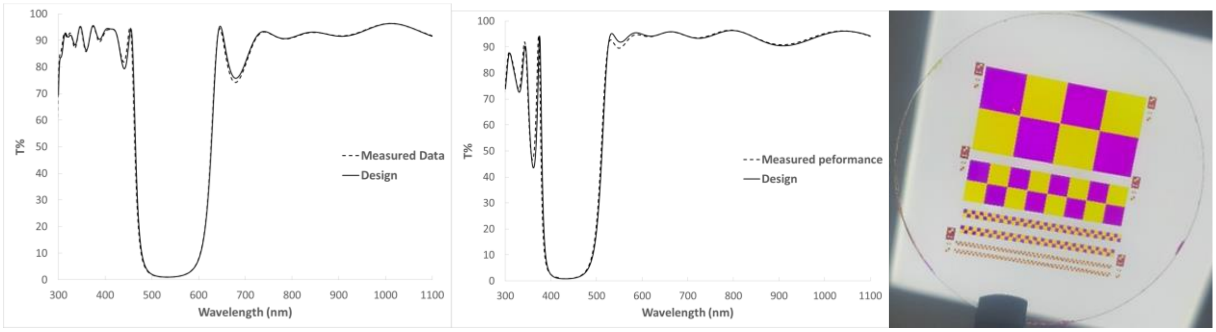

Fig. 2a. Transmission of Magenta filter. 2b. Transmission of Yellow filter. 2c. Image of dual colour patterned filter.

2.2. Filter separation

Channel separating filters was imaged using both optical microscope and scanning electron microscope. Samples were cleaved to give a cross-section for SEM. Images are shown in figure 3.

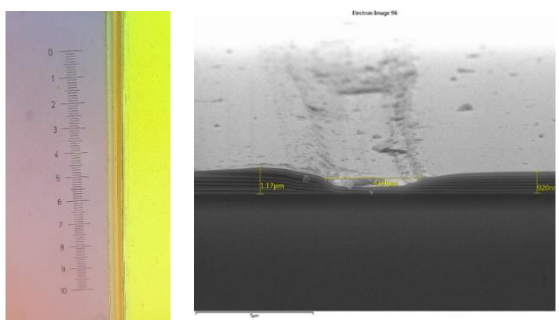

Fig. 3a. Optical microscope image of filter channel 5X magnification. 3b. SEM image of channel 4000X mag.

SEM image shows filter separation of 4.04µm. It can also be seen that filter layers overlap into the channel. This is confirmed by the interferences fringes seen on the optical microscope. This is due to either mask misalignment or material being deposited in the undercut of the photoresist due to surface diffusion.

3. Conclusion

In this work a dual colour patterned filter has been designed and fabricated using by low temperature microwave plasma assisted pulsed DC sputtering (MPAS) and photolithography. Compatibility between these 2 processes has been demonstrated.

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