High throughput microwave plasma assisted sputter deposition of linear variable filters and deployment into visible and near infrared spectrometers

Fleming, Lewis; Gibson, Des; Song, Shigeng; Hutson, David; Ahmadzadeh, Sam; Cai, Sijia; Han, Daxing; Waddell, Ewan; Saffell, John

Published in:
Optical Interference Coatings Conference (OIC) 2022

DOI:
10.1364/OIC.2022.ThC.4

Published: 01/01/2022

Document Version
Peer reviewed version

Citation for published version (APA):
Fleming, L., Gibson, D., Song, S., Hutson, D., Ahmadzadeh, S., Cai, S., Han, D., Waddell, E., & Saffell, J. (2022). High throughput microwave plasma assisted sputter deposition of linear variable filters and deployment into visible and near infrared spectrometers. In R. Sargent, & A. Sytchkova (Eds.), *Optical Interference Coatings Conference (OIC) 2022* [ThC.4] (Technical Digest Papers). Optica Publishing Group (formerly OSA). https://doi.org/10.1364/OIC.2022.ThC.4

High throughput microwave plasma assisted sputter deposition of linear variable filters and deployment into visible and near infrared spectrometers

Lewis Fleming[1,2], Des Gibson[1,2], Shigeng Song[1,2], David Hutson[1,2], Sam Ahmadzadeh[1], Sijia Cai[1], Daxing Han[1], Ewan Waddell[2], , John Saffell[3]

[1]Institute of Thin Films, Sensors and Imaging, Scottish Universities Physics Alliance, School of Computing, Engineering and Physical Sciences, University of the West of Scotland, Paisley, PA1 2BE, Scotland, UK.
[2]Albasense Ltd. Paisley, PA1 2BE, Scotland, UK
[3]NosmoTech Ltd, Cambridge, CB3 0AZ, England, UK

Corresponding Author: lewis.fleming@uws.ac.uk

Abstract: Fabrication of linear variable filter (LVF) designs are demonstrated using a high throughput drum with linear sputter targets and static graded uniformity masks. Optical performances are characterised and functionality tested in 3D printed miniature spectrometers.

OCIS CODES: (310.1860) Deposition and fabrication; (310.3840) Materials and process characterization; (310.1860) Thin films, optical properties

Introduction

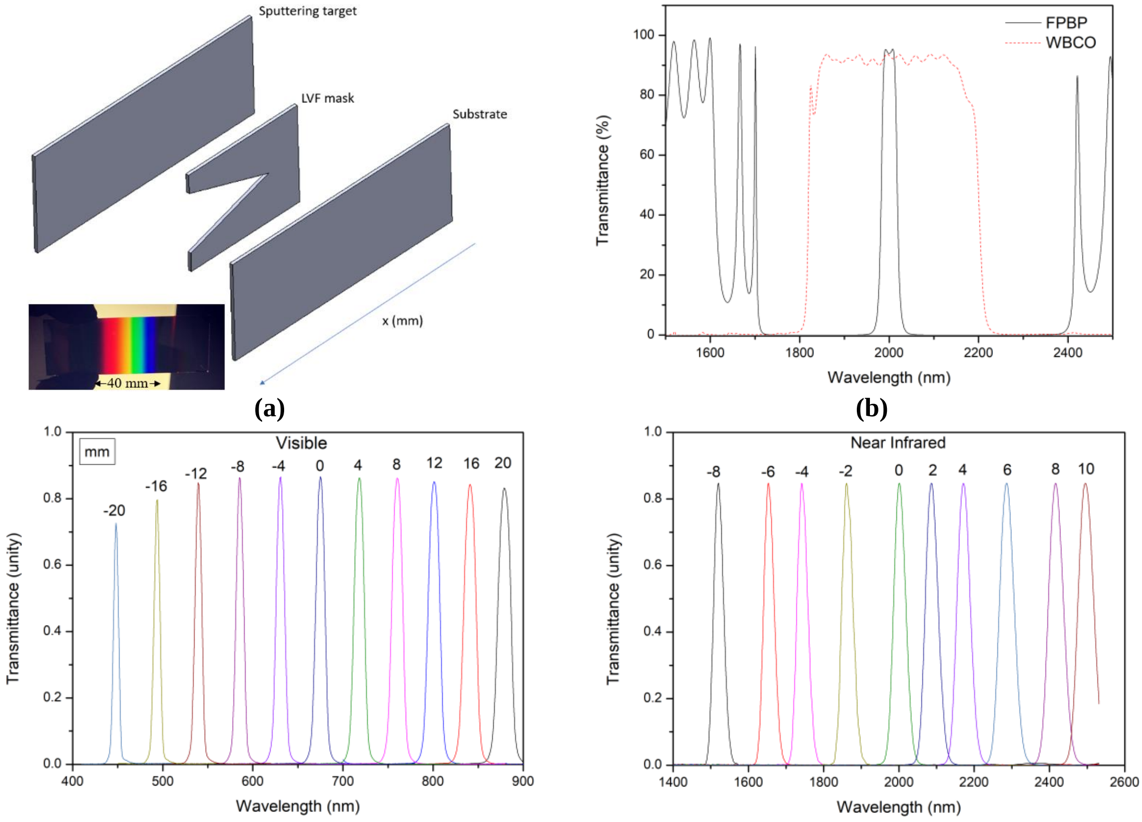
Spectroscopic optical applications typically use dispersive elements such as diffraction gratings to separate light into its constituent wavelengths for spectral analysis. However, as gratings disperse the light as a function of angle, complex optical designs and a large footprint are required to allow the dispersion of light across a detector. For applications where compactness, ruggedness and low cost are desired, linear variable filters have become an attractive alternative [1].

An LVF is an optical filter whose spectral characteristic grade linearly with spatial position along the length of the filter and can easily be integrated into optical systems due to their low weight and miniaturised configuration. LVFs can be fabricated to have a tailored bandpass transmittance, bandwidth, out of band blocking and compact structure making them a desirable alternative to traditional gratings for integration into miniaturised optical systems requiring spectral selection over visible, near-infrared (NIR), mid-wave infrared (MWIR) or long-wave infrared (LWIR) wavelengths. LVFs are powerful candidates for optical system designs that are limited by environmental conditions and cost such as those deployed in industrial manufacturing and aerospace applications. Moreover, LVFs are advantageous compared with discrete multi-channel bandpass filters, due to their ability to operate over a continuous waveband.. Determination of wavelength range and physical filter size is a straightforward selection of; coating material choice, multilayer optical filter design and coating mask methodology. In this work, a high throughput drum-based pulsed DC microwave plasma assisted sputtering (MPAS) technique is used with linear magnetrons and static spatially graded uniformity masks. This provides LVF gradient control [2]. Such a method is simple and advantageous over traditional LVF fabrication methods such as ion beam sputtering [3] that require complex dynamic masking arrangements [4].

To demonstrate flexibility in achieving LVF designs using the MPAS static mask technique [2], two different LVFs are fabricated – a 40 mm length LVF operating in the visible (450 nm – 900 nm) with spectral resolution $\Delta\lambda_0 = 8$ nm and a 23 mm length LVF operating in the NIR (1500 nm – 2500 nm) with $\Delta\lambda_0 = 35$ nm. LVF deployment into portable, low-cost field deployable miniature 3D printed spectrometers is described.

Experimental Results

The MPAS process employs a horizontal drum with pulsed DC sputtering from a fixed linear magnetron with the sputtered flux passing through a static mask and incident on substrates mounted on drum plates (figure 1a). In a separate spatial location, reactive gas is ionised via 2.45 GHz microwave power, uniformly oxidising the separately deposited layers [5]. Design methodology for both visible and NIR LVFs include a double side coated filter design with a 3-cavity Fabry-Perot bandpass (FPBP) on one face of the substrate and an optimised wide band cut-off (WBCO) filter on the opposite face (figure 1b). The FPBP has a FWHM of 1.5 – 1.75% of the passband centre wavelength and permits a narrow wavelength selection, whereas the WBCO enables rejection of unwanted side bands, with OD 3 out-of-band blocking. High and low index coating materials used for both designs were Nb_2O_5 and SiO_2 respectively. The wavelength range ($\Delta\lambda$) and the LVF length (Δd) are chosen,with required coating thickness gradient obtained from the modelled filter design. Resulting linear dispersion coefficient, $\Delta\lambda/\Delta d$, is 10.8 nm/mm and 42.5 nm/mm for the visible and NIR LVF designs respectively.



(a) **(b)**

(c) **(d)**

Figure 1. (a) Schematic of sputter masking to yield a linearly graded coating thickness distribution across the x-axis of the substrate (inset: image of fabricated visible LVF) and **(b)** modelled optical transmittance of FPBP and WBCO filters on either side of a glass substrate at the centre of the NIR LVF **(c)** optical transmittance spectra measured at various positions across length (x-axis) for 40 mm length LVF with range in the visible (400 nm – 900 nm) and **(d)** 23 mm length LVF with range in the NIR (1500 nm – 2500 nm).

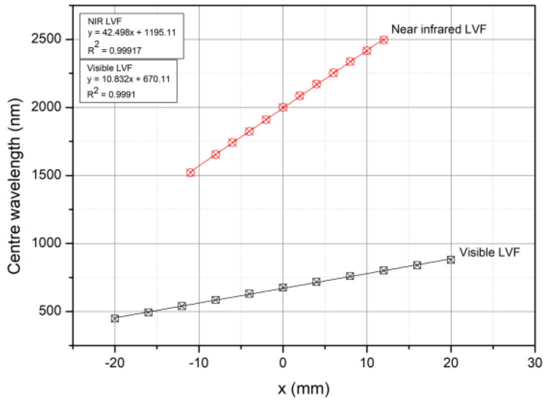
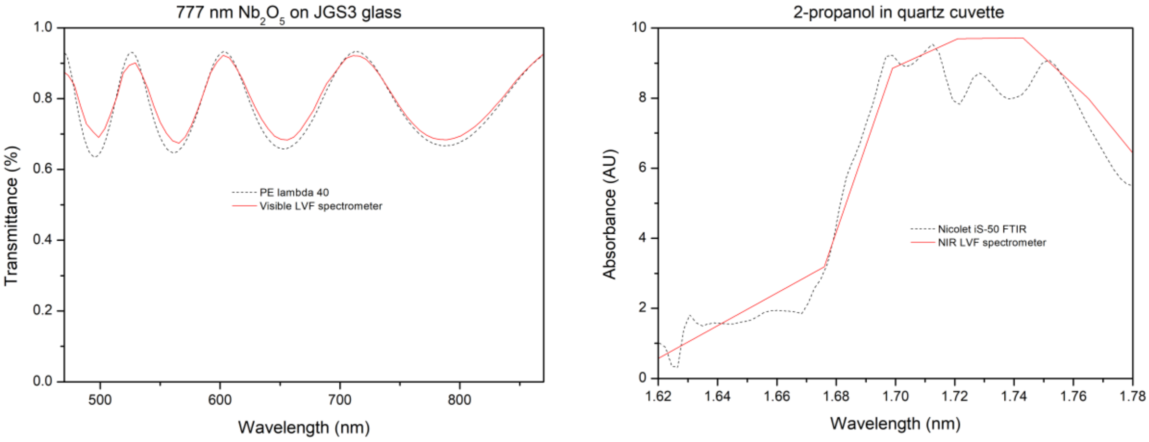


Figure 2. Linear fits for centre wavelength versus filter x-axis position for the 23 mm NIR LVF and the 40 mm visible LVF.

Figures 1c and d show the measured optical transmittance spectra at different locations across both the 40 mm length visible and 23 mm length NIR LVFs. The LVF centre passband wavelength is plotted against the position across the length of the filter (x-axis) for both filter designs (figure 2). From linear fitting of the discrete data points, excellent linearity is achieved with both R^2 values equal to 0.999. In addition, the respective slopes obtained for the visible and NIR linear fits are 42.49 and 10.83 which is in excellent agreement with the modelled linear dispersion coefficients.



(a) **(b)**

Figure 3. 3D printed visible and NIR LVF spectrometer scans compared with commercial benchtop spectrometer scans **(a)** thin film Nb_2O_5 on JGS3 glass and **(b)** liquid 2-propanol in quartz cuvette.

To demonstrate functionality, the LVFs were built into 3D printed optical spectrometer chassis', fitted with linear LVF translational drives to control position. Spatial location on the LVF was mapped onto the transmitted wavelength. Test samples of thin film Nb_2O_5 on JGS3 glass and 2-propanol were scanned using commercial benchtop spectrometers in the visible and the NIR respectively and compared with the visible and NIR 3D printed spectrometer devices. Good agreement between the spectral measurements is indicated in figure 3, demonstrating the successful integration of LVFs into low cost and rapid prototyped miniature spectrometers.

Conclusions

In this work a high throughput drum-based method of fabricating double side coated narrow bandpass LVFs with $T \geq 85\%$ and OD 3 out-of-band blocking is described. Two different wavelength ranges, physical lengths and hence linear dispersion coefficients (visible, 10.83 nm/mm and NIR, 42.49 nm/mm) were demonstrated, highlighting the flexibility of the MPAS LVF deposition technique, producing LVFs with different characteristics that can be tailored to serve as a solution for any application requiring spectral selection where cost, weight and spatial footprint are tightly restricted. To demonstrate this, the LVFs fabricated in this work were integrated into 3D printed spectrometer devices and scans validated by comparison with widely used commercially available benchtop dispersive spectrometers. Using different material combinations MPAS deposited LVF wavelength range can be extended to MWIR and LWIR wavebands

Acknowledgements

The author wishes to express gratitude towards Innovate UK, where part of this work was undertaken in partnership with Alphasense Ltd as part of a Knowledge Transfer Partnership project, number 11467.

References

[1] Tang, H.; Gao, J.; Zhang, J.; Wang, X.; Fu, X. Preparation and Spectrum Characterization of a High Quality Linear Variable Filter. *Coatings* 2018, *8*, 308. https://doi.org/10.3390/coatings8090308

[2] S Song, D Gibson,"Apparatus and Methods for Depositing Variable Interference Filters", patent application number GB1702478.7 Filing date 15th February 2017

[3] Emadi, A.; Wu, H.; de Graaf, G.; Wolffenbuttel, R. Design and implementation of a sub-nm resolution microspectrometer based on a linear-variable optical filter. Opt. Express 2012, 20, 489–507.

[4] Cheng Li, Shigeng Song, Des Gibson, David Child, Hin on Chu, and Ewan Waddell, "Modeling and validation of uniform large-area optical coating deposition on a rotating drum using microwave plasma reactive sputtering," Appl. Opt. 56, C65-C70 (2017)

[5] A. T. Laëtitia, F. Lemarquis, and M. Lequime, "Masking mechanisms applied to thin-film coatings for the manufacturing of linear variable filters for two-dimensional array detectors," Appl. Opt. 47, 5706–5714 (2008).