Transmission spectra characterization of nano-patterned guided-mode-resonance color filters

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Summary

Nano-patterned color filters based on periodic subwavelength metal gratings have been fabricated to be employed for sharp transmissions. The measured spectra using a micro-spectrometer were compared to RCWA-based simulations. Narrow linewidth and low sidebands were observed in both measured and simulated spectra.

Introduction

Nowadays, the major trends in optical metrology are greater data density for many complex applications. For instance, in the biomedical field, where light is the most powerful tool for non-invasive continuous health diagnostics, a full spectral response of the tissue and blood can be used for precise relevant health data determination. In this case, a sensing system with spectrometer functionality is very desirable. This can be realized by using a CCD or CMOS image sensor covered by a color filter matrix, which consists of microscale nano-patterned filters. The filter functions can be controlled from pixel to pixel. Because of their owned properties of high transmission, narrow linewidth, and low sideband, filters based on metal gratings and dielectric waveguide with guided-mode resonance (GMR) behavior [1] are very suitable for this system. As the resonance of a GMR filter mainly depends on its structural parameters (Fig. 1), different filter functions have been therefore realized by varying the influencing parameters (e.g., the grating period and filling factor).

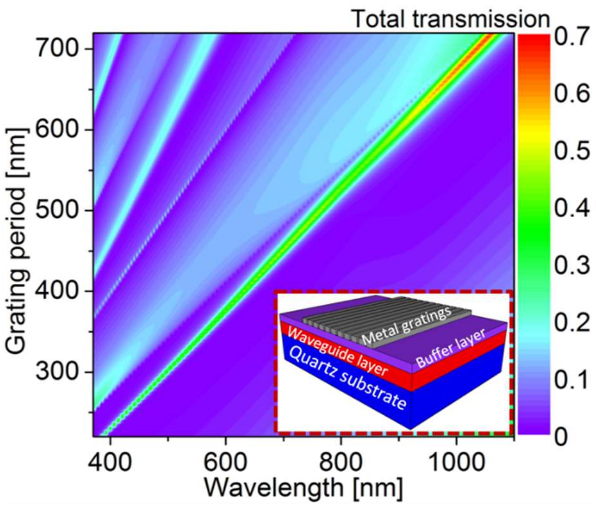

Fig. 1. Simulated transmission spectra of GMR color filters with grating period ranging from 220 nm to 710 nm, covering the wavelength from 380 nm to 1100 nm. Inset shows a filter architecture involving periodic metal gratings.

Discussion

The transmission spectrum of GMR filters with different grating periods have been simulated and the results are shown in Fig. 1. The transmission peak wavelength shifts from 380 nm to 1100 nm, while the grating period is varied from 220 nm to 710 nm. To verify the simulation results, a color filter matrix as well as two rectangular filters were fabricated using e-beam nanolithography (Fig. 2(a)). Afterwards, by using ellipsometry,

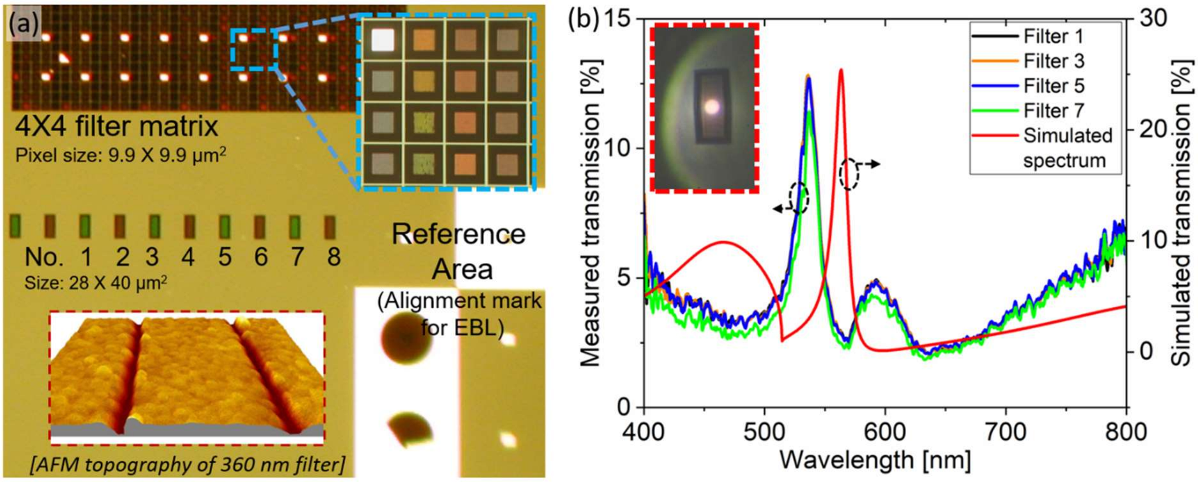

Fig. 2. (a) Back illuminated microscope images of the fabricated filter matrix (upper part) consisting of 15 individual filters and a hole cell without metal coating, as well as two rectangular filters (middle part) having periods of 360 nm (green) and 600 nm (red). An AFM topography image was shown in the lower part. (b) Measured and simulated transmission spectra of green filters with V-shaped gratings. Inset is the back illuminated filter during measurement.

SEM and AFM, the structural parameters were determined to be 84.5 nm, 49.2 nm, and 41 nm for waveguide layer thickness, buffer layer, and grating depth, respectively. The green rectangular filter has a period of 352 nm and filling factor of 0.842. The gratings have a V-shaped gap instead of the designed and expected sharp edges.
Because of the tiny filter size, specifically designed measurement setup based on highly precise microscope combined with a fiber spectrometer (suitable to measure the transmission in a field area as small as 1 μm) was used for local transmission measurements. The results of different green filters in comparison to the simulation result with characterized structural parameters are depicted in Fig. 2(b). We can easily find that the simulated transmission of filter with V-shaped gap is reduced to 25% because of an additional optical power loss at those gaps. Nevertheless, all four fabricated filters have very similar spectrum transmission of ~13%, which shows a good reproducibility. Moreover, as expected, both measured and simulated spectra have a narrow bandwidth. In regards to wavelength selective filtering performance, a peak shift of ~30 nm (i.e., from 565 nm to 535 nm) can be observed, in which the sideband of the measured spectra is lower than that of simulated. The oxidation of metal gratings as well as its rough surface could possibly be two reasons to explain this phenomenon.

Conclusions

In conclusion, the proposed color filter matrix featuring subwavelength metal gratings has been fabricated by e-beam nanolithography technology. The structural parameters of fabricated filters were measured, in which an adapted spectrum transmission simulation had followed to compare the characterization and simulation results. In this case, the measured and simulated transmissions of green filters are 13% and 25%, respectively. Both spectra have very narrow linewidth. Higher transmission efficiency can be realized by optimizing the device fabrication process (e.g., to create grating gaps with perpendicular profiles instead of V-shaped structures).

References

[1] Alex F. Kaplan, Ting Xu, and L. Jay Guo, *Applied Physics Letters*, **99**, 143111, 2011