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E-beam lithography exposure conditions for the fabrication of RGB filter based on metal/dielectric subwavelength grating

S A Fomchenkov[1,2], M A Butt[1], V V Podlipnov[1,2], S D Poletaev[1,2], R V Skidanov[1,2], N L Kazanskiy[1,2]
[1]Samara State Aerospace University, Moskovskoye Shosse 34, Samara, 443086, Russia
[2]Image Processing Systems Institute of the Russian Academy of Sciences, Molodogvardeyshaya 151, Samara, 443001, Russia

Abstract. The main idea of this work was to determine the optimized parameters of E-beam lithography to obtain metal grating over dielectric thin film. This combination of metal/dielectric can provide high transmission spectrum of RGB colors. Different electric flux densities were used during E-beam writing and the best resolution and symmetric periodicity was obtained at 53 µC/cm^2 dose.

1. Introduction
Colour filters are playing important role as a key element for wide area of applications such as light emitting diodes (LED), liquid crystal displays (LCD) and antireflection filters [1,2]. In order to meet the demanding market requirements for large display panels, it is mandatory to make the color filter thinner, larger and easy to fabricate. In this work, we have presented the steps of fabrication of the RBG color filter and studied the effect of various power intensities of e-beam writing system on E-resist at nanometer scale resolution.

2. Experimental details
In this section, the fabrication steps of RGB filter are presented. The schematic of the total fabrication steps are shown in figure 1.

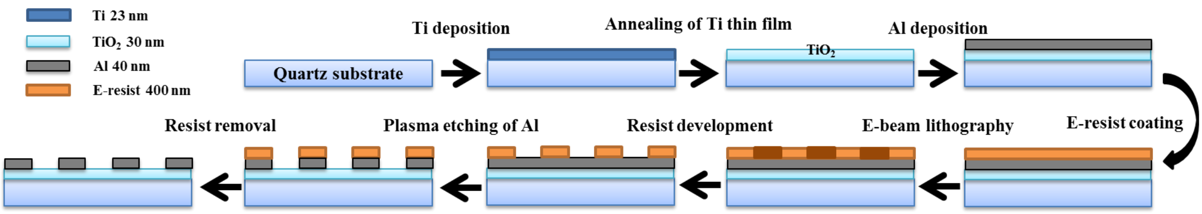

Figure 1. Fabrication steps of RGB filter.

2.1. Deposition and oxidation of Ti layer
Ti thin film was deposited on quartz with the help of magnetron deposition system Caroline D12A. For all deposition experiments, we used DC power of 300 W, 2x10^{-5} Torr and the gap between substrate/target was 100 mm. The adhesion of Ti films was improved by heating the substrate but the

film morphology strongly depends on the substrate temperature during the deposition process. Ti films of 80-200 nm was deposited for morphological and optical characterization.

Usually, Ti thin films deposited below150 ^{o}C are amorphous and attain crystallinity after annealing process. TiO_2 was obtained by high temperature annealing (oxidation) of Ti films. Annealing process was carried out in muffler furnace by using Conventional Thermal Annealing (CTA). The samples were loaded in the muffler at room temperature and slowly heated till 700 ^{o}C and then maintain the temperature for 1 hr. Once the annealing was complete, the temperature was reduced till room temperature with a slow ramp. In order to obtain rutile phase of TiO2, the annealing was done between 500-700 ^{o}C for 1-2 h. After annealing, the obtained TiO_2 films were fully transparent which can be observed visually.

We tried to investigate the effect of substrate temperature during deposition of Ti layer. Substrate temperature of 50 and 150 ^{o}C were used during Ti metal deposition to test the adhesion and scratch of the layer. After several attempts of tape test, it was confirmed that, Ti layer deposited at both 50 and 150 ^{o}C showed good adhesion on quartz.

Ti thin film of 120 nm was deposited on quartz substrate at 50 and 150 ^{o}C and annealed at 600 ^{o}C for 1 h. From SEM images, it can be observed that TiO_2 layer obtained after annealing at 600 ^{o}C (substrate temperature of 150 ^{o}C) has comparable less surface roughness as compared to the TiO_2 film obtained after annealing (substrate temperature 50 ^{o}C) as shown in figure 2 (a) and (b). These films are smooth and can be used in the fabrication of various optical components.

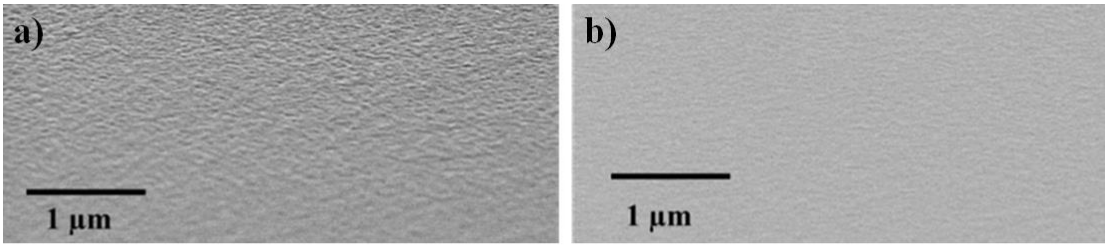

Figure 2. SEM images of the surface morphology of TiO_2 on quartz substrate obtained after annealing at 600 ^{o}C (a) substrate temperature 50 ^{o}C, (b) 150 ^{o}C.

2.2. Optical characterization

To verify the phase of annealed thin TiO2 films deposited on quartz substrate, we carried out Raman spectroscopy and obtained one weak Raman shift peaks at 143 and two strong peaks at 447 and 612 cm^{-1} which indicates rutile phase as shown in figure 3.

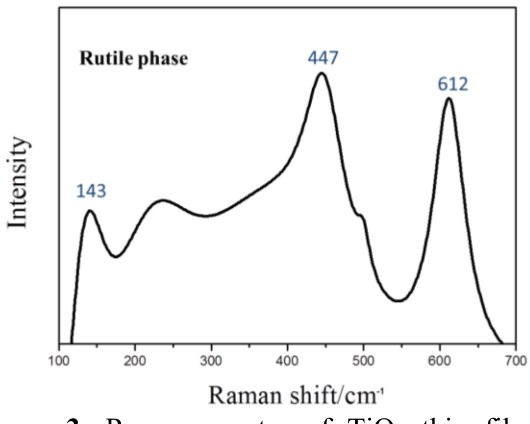

Figure 3. Raman spectra of TiO_2 thin film converted by annealing Ti layer deposited on quartz substrate (substrate temperature 150 ^{o}C).

Refractive index of TiO_2 layer of same thickness deposited on quartz substrate annealed at different temperatures (500 and 700 ^oC) was measured.

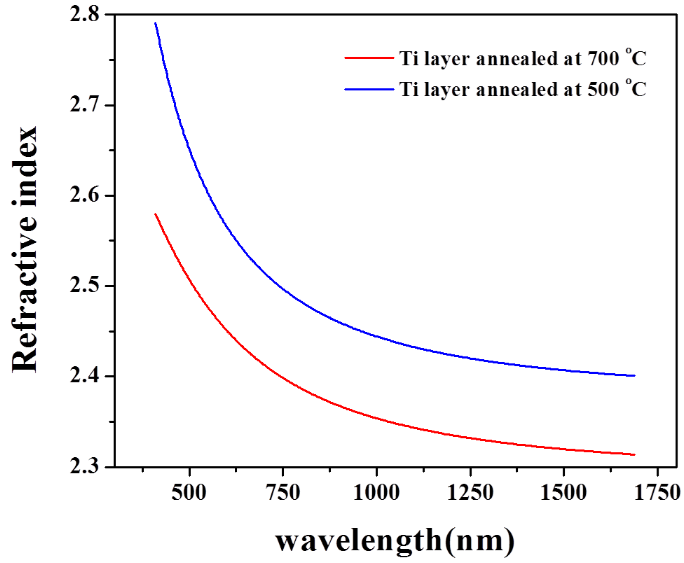

Figure 4. Refractive index measurement of TiO_2 layer on quartz substrate.

From figure 4, it can be observe that, the TiO_2 films on quartz substrate annealed at 500 ^oC has higher refractive index range as compared to sample annealed at 700 ^oC. The gradient in refractive index can be due to the expansion of layers at different ratio during annealing at different temperature. Transmittance spectra were measured in the wavelength range of 350-1600 nm. For the visible wavelength range, the transmittance is around 75%.

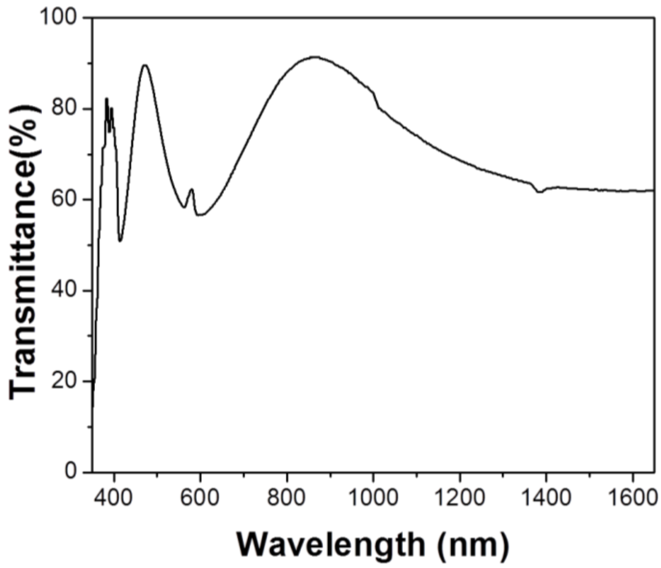

Figure 5. Transmittance spectrum of TiO_2 deposited on quartz.

The optical properties of TiO_2 film deposited on quartz substrate were measured with the help of Ellipsometer M2000DI.

2.3. E-beam lithography

The sample was coated with electron positive resist (EPR-40) at 5000 rpm to obtain 400 nm layer. The grating design was written on resist at different electric flux density as mentioned in table 1.

Table I. E-beam dose and actual size of RGB gratings.

E-beam dose ($\mu C/cm^2$)	**Actual size(nm) Period/Duty cycle**		
	Red	**Green**	**Blue**
	420/231	350/193	260/143
47	Underexposed	Underexposed	Underexposed
50	430/234	360/188	260/137
53	434/215	362/165	259/139

From the table, it can be observe that the resist is underexposed at doses less than 50 $\mu C/cm^2$. The design closest to the actual parameters was obtained at dose level of 50 $\mu C/cm^2$. The SEM images of the grating fabricated on resist after development is shown in figure 6.

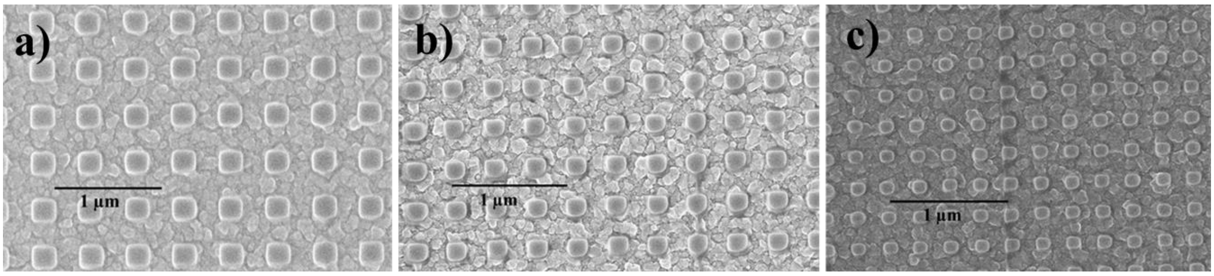

Figure 6(a, b, c). SEM images of the RGB grating fabricated at 50 μC/cm2 dose on resist **(a)** Red, **(b)** Green, **(c)** Blue.

3. Conclusion

In this work, we obtained transparent oxide layer by annealing Ti layer which is the fundamental basis to increase the transmission efficiency of RGB filter. Titanium metal layers deposited by magnetron sputtering on different substrates were converted into titanium dioxide rutile phase at 500-700 ^oC. Polycrystalline phase was determined by Raman spectroscopy. Surface morphology of the dielectric film deposited on different substrates was observed by SEM and found the low surface roughness on quartz substrate and the maximum transmittance when the deposition temperature of Ti metal layer was 150 ^oC. Transmittance could be enhanced substantially through the surface plasmon resonance induced at the dielectric-metal interfaces. This filter was fabricated on EPR with E-beam lithography at different electric flux densities with an accuracy of 10 nm. The best resolution and symmetric periodicity was obtained at 53 $\mu C/cm^2$ dose.

Acknowledgments

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