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Thin film optical filter fabrication and characterization

Adam G. Hammouda
Kalamazoo College

David P. Shelton
University of Nevada, Las Vegas

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Adam G. Hammouda[1] and Dr. David P. Shelton[2]

[1]Department of Physics, Kalamazoo College, Kalamazoo, MI 49006, USA

[2]Department of Physics, University of Nevada-Las Vegas, Las Vegas, NV 89154, USA, NSF REU Program Summer 2008

Background:

Thin film coatings have a large number of applications. For example, one can eliminate unwanted reflection on a photographic lens or unwanted wavelengths of light in optics experimentation. The fabrication and characterization of films whose refractive indices can be arbitrarily modulated ('Rugate Filters') is an ongoing exploration in materials science[1,2]. Therefore, calibrating a process which can manufacture such films is a relevant pursuit in forwarding such explorations

Reactive magnetron sputter deposition is a commonly used technique for the productions of thin films[3,4]. This technique steadily flows reactive gas (RG) into a vacuum chamber in which an electric field has been established. The RG is then ionized by the electric field which causes it to bombard a solid target placed inside the chamber. Many of the atoms which are displaced by the ionized gas further travel towards an adjacent substrate (Figure 1). Ideally, this occurs in such a way as to deposit the newly formed molecule on the surface a glass slide. In our case the RG, N_2, and O_2 were intended to deposit Si_3N_4 and SiO_2 whose indices of refraction are respectively high and low (Figure 4). Reproducibility of this contrast is essential in the fabrication of the desired optical devices.

In order to determine that these intended reactions occurred in a reproducible way, the thickness and refractive index of the films where calculated from the Transmission Spectra of the films.

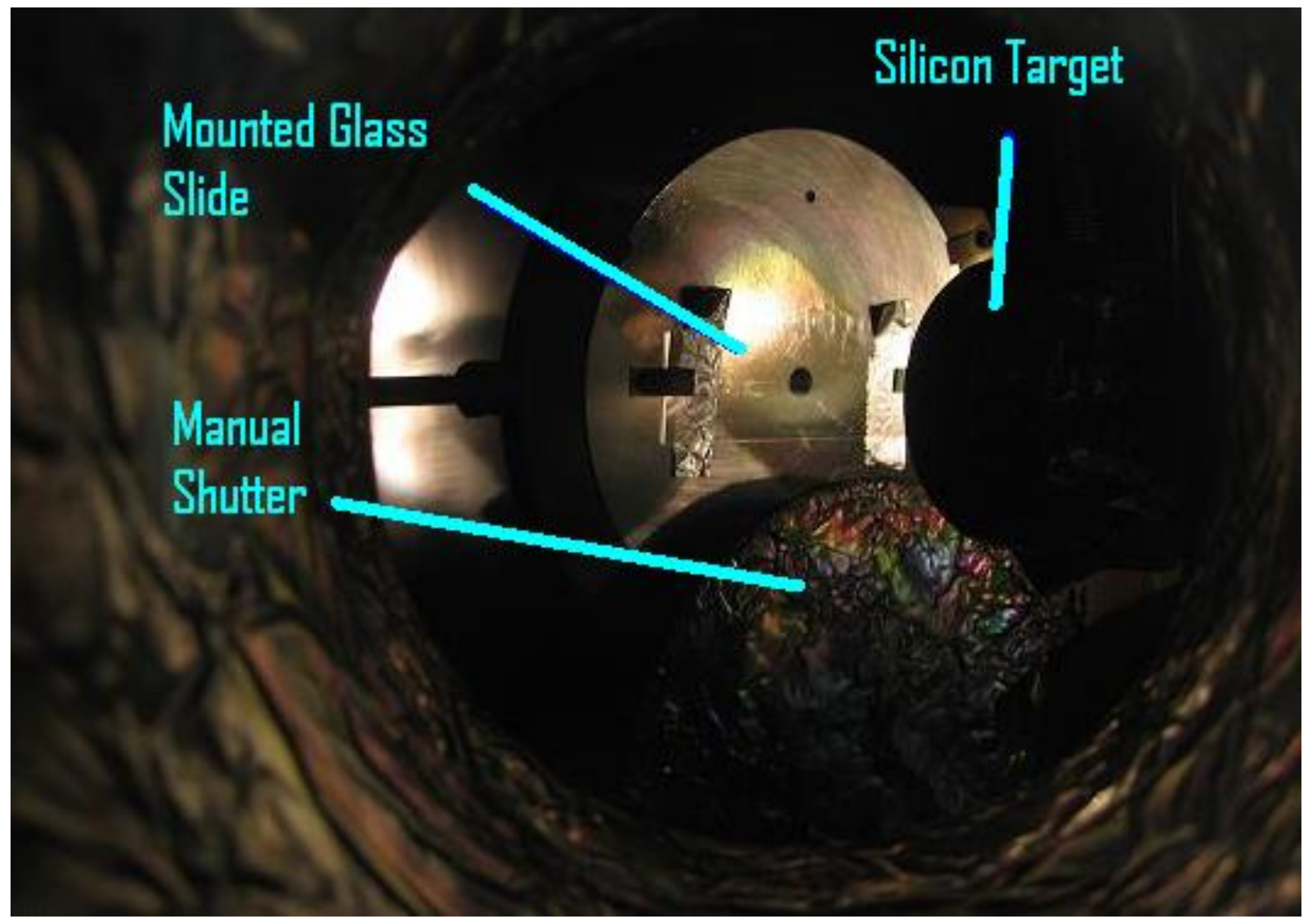


Figure 1: A view of the deposition system through one of portals of the vacuum sealed bell jar chamber. Depicted is the silhouette of the silicon target (right) adjacent to the blank glass slide (left) on which a deposition is to occur. Beneath, one can make out a good part of the target's shutter at half mast.

Experimental Details

For all of the films made a vacuum deposition system was used. The base pressure of the system was 1.0 x 10^{-6} torr. Every deposition was performed in an Ar environment at pressures of 7-8.5 mtorr flowing RG, N_2 and O_2 at varied ratios. The rf power applied to the target was always maintained at 150 W. All depositions were done on glass microscope slides, and were started and stopped using the manual shutter (Figure 1). Transmission Spectra were taken by a UV-Visible Spectrophotometer over wavelengths (λ) from 200 – 900 nm (see Acknowledgements).

Thin Film Analysis:

Two questions one should be able to answer in order to effectively produce thin films are:

- What exactly is it that is being deposited under different conditions?
- How fast is the deposition occurring under the given conditions?

Both of these things can be determined through analysis of the transmission spectra of a deposited film (Figure 2a,b). From these spectra one can determine the refractive index of a film (n) given by:

$$\sqrt{R_{\min}} + \sqrt{R_{\min}} = 2 \bullet \left| \frac{n_{film} - n_{air}}{n_{film} + n_{air}} \right|$$

Where n_{film} and n_{air} are the refractive indices of the deposited film and air, respectively. R_{max} and R_{min} are the Maximum and Minimum Reflectance of the deposited film corresponding to the respective minimum and maximum transmittance (Figure 2b). Using the previously calculated refractive indices the thickness (t) of a deposited film can be determined:

$$\frac{t \bullet n_{film}}{\lambda_{\max}} = \frac{t \bullet n_{film}}{\lambda_{\min}} + \frac{1}{2}$$

Where λ_{max} and λ_{min} correspond to the wavelengths at which the transmission of the film is respectively maximal or minimal. The + ½ term corresponds to the ½ period of oscillation which the channeled spectrum's transmittance undergoes between a maximal and minimal value.

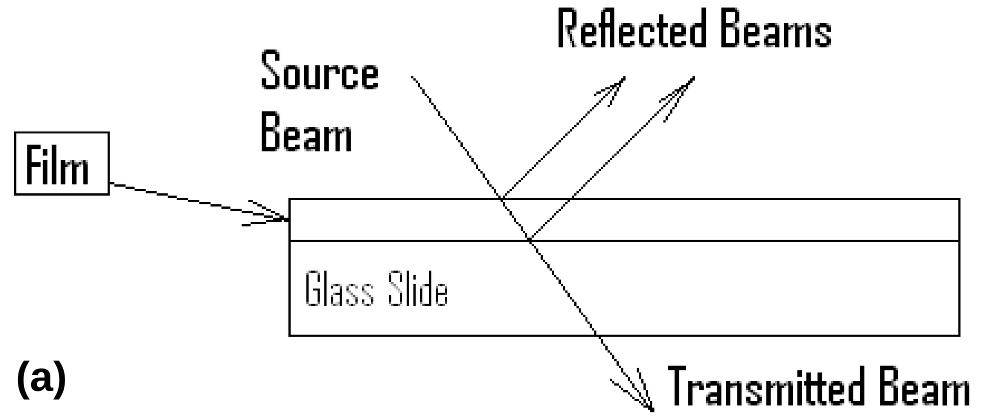
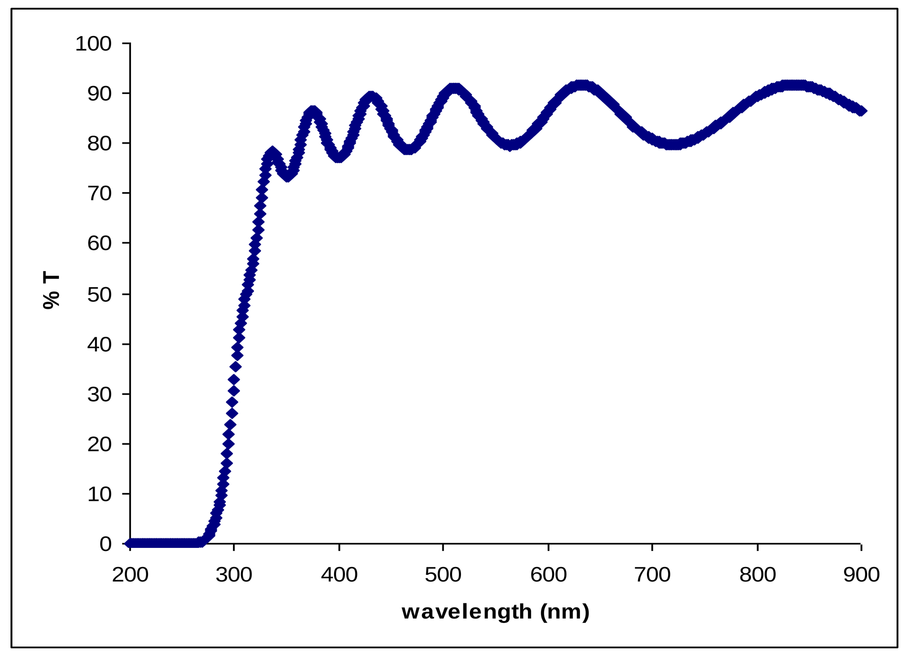


Figure 2: **(a)** A cross sectional representation of a thin film deposited on glass. Single reflections at the air-film and film-glass interface are considered. Constructive interference of the two reflected beams maximizes at a minimum transmittance and the reverse is also true.



(b) An example of a 'channeled' transmission spectrum taken from a film deposited with N_2 as the RG. The drop to 0 % transmittance (%T) corresponds to the absorption of the glass microscope slide. The average thickness calculated from this spectrum was 676 nm while its refractive index ranged from 1.89 – 2.07 from wavelengths of 836 – 400 nm.

References

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Results and Discussion

Using the above analysis a deposition rate was extrapolated (Figure 3). Moreover, an indication of the purity of the material we have deposited can be obtained from a comparison of the dispersion of our deposited material with literature values[5] (Figure 4). The deviations in refractive index of deposited Si_3N_4 is conceivably due to differences in fabrication technique, limitations of the index calculation used (seems especially so at shorter wavelengths), and/or the presence of residual air molecules interfering with the desired reactions.

Despite any shortcomings in the refractive indices, it is clear from (Figure 4) that they are consistently higher and lower. Using this contrast and the deposition rate for the respective RG, two high reflectivity mirrors targeted for λ = 633 nm & 532 nm were fabricated using the condition that (t x n)/(λ = 633, 532) = ¼ where t and n are as given above. Ten layers of the high/low refractive index alternated continuously had mixed success (Figure 5a, b).

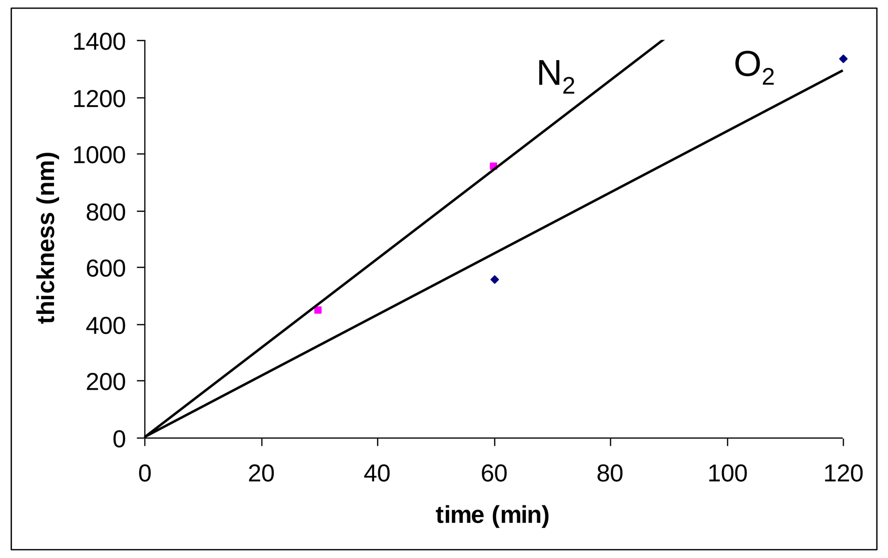

Figure 3: A rough deposition rate for compounds Si_xN_x (likely Si_3N_4) and Si_xO_x (desired: SiO_2). The reactive gas for each deposition type is listed next to its extrapolated fit. The deposition rate of Nitrogen is approximately 15.7 nm/min. For Oxygen, 10.8 nm/min.

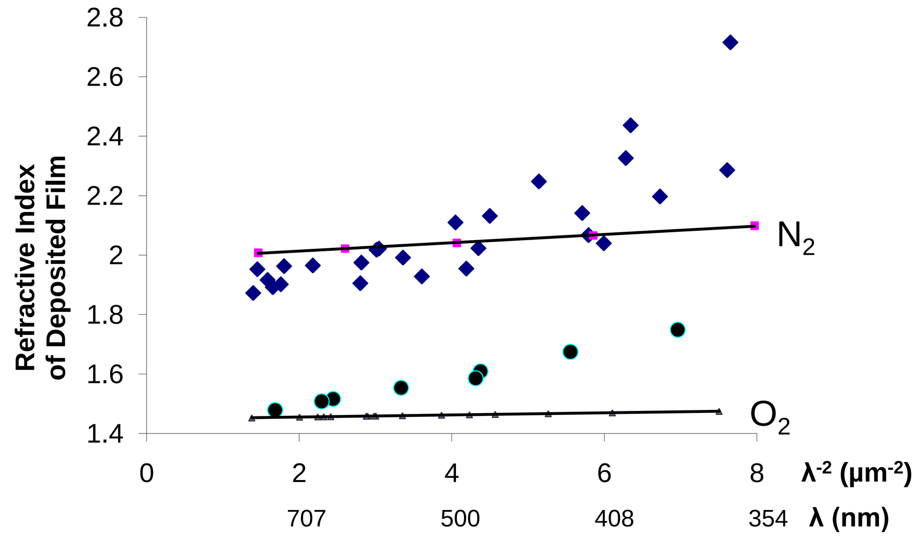

Figure 4: The dispersion of deposited Si_xN_x (likely Si_3N_4) and Si_xO_x (desired: SiO_2). The RG for each deposition type is listed adjacent to the refractive indices of their corresponding material. The literature dispersion values for the respective RG have a line drawn through them.

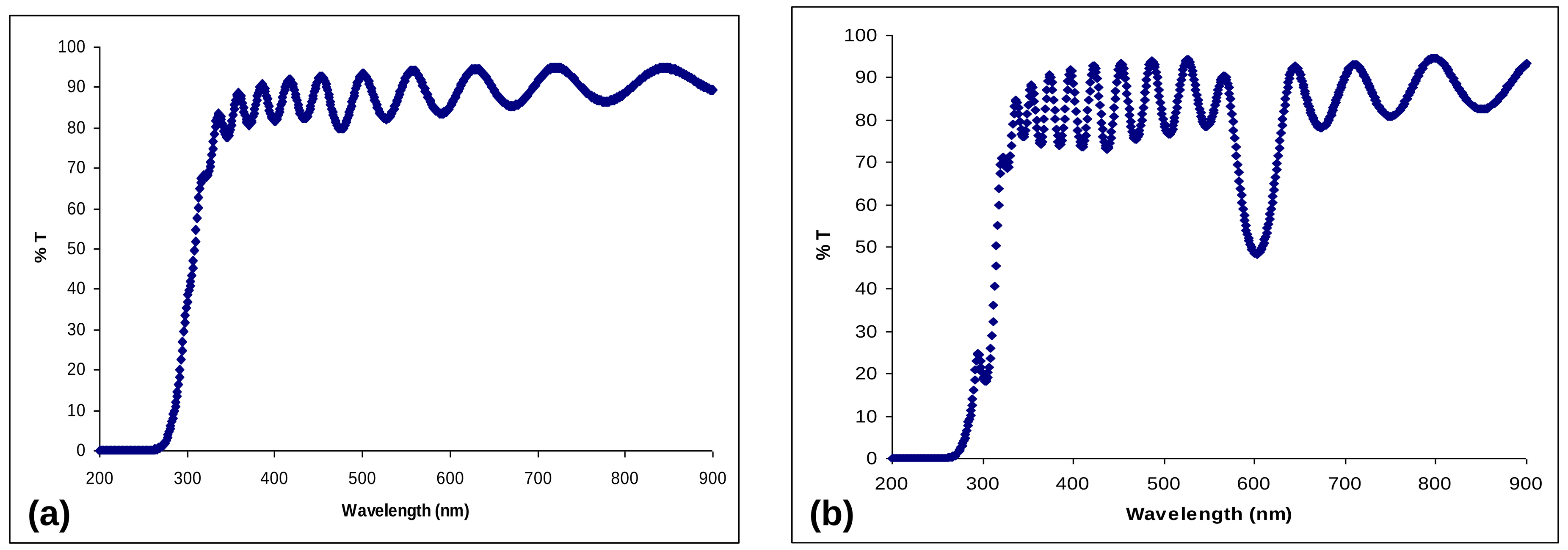

Figure 5: The transmission spectra of high reflectivity mirrors targeted for λ = 532 **(a)** and 632 **(b)** nm. The lack of a significant stop band at 532 nm on **(a)**, while a weak stop band is visible from λ = 565-645 nm in **(b)** indicates a weak contrast in the refractive indices of the deposited layers in **(a)** relative to **(b)**. Moreover the amplitude of oscillation in spectrum **(a)** is clearly smaller on average than is seen in **(b)**. This further indicates that the lower refractive index species has predominated in mirror **(a)** relative to **(b)**. These spectra therefore provide a strong indication that the change in the target deposition conditions when alternating between N_2 and O_2 RG (depositing ideally Si_3N_4 and SiO_2 respectively) occur slower than variable material layers are formed.

Conclusions

We have been able to make a weakly reflective mirror targeted for λ = 633 nm. We believe that the weakness of the reflection is due to the fact that the Si target conditions change slower than material layers are formed. This can easily be tested for by designing a mirror targeted for a longer wavelength (λ = 800 nm). If a stop band is observed in this location which reflects closer to 100% of the source light, this hypothesis would be proven correct.

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