A Chrome AR Film for Binary Photomasks

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Abstract- A photomask typically consists of a bulk transparent substrate and a thin metallic film with etched pattern on the surface for light absorption. Stray light reflecting off of the top surface of the photomask is especially problematic because it is focused onto the wafer surface, causing unwanted exposure of the photoresist. . Lithographic performance can be significantly improved if this reflection is reduced with an antireflective layer on the top surface of the photomask. There are commercially developed antireflective films for chrom based photomasks. These films were designed to meet certain specifications for optical density and reflectivity. The goal of this project was to develop a process to replicate these commercial films at RIT. X-ray Photoelectron Spectroscopy (XPS) was performed on the commercial samples to obtain depth profiles of the atomic constituents of the chrome-based films. Absolute reflectivity and transmission data were obtained on these films using a Perkin-Elmer Lamba-11 UV/VIS Spectrophotometer. Finally, a sputter deposition process was developed to deposit a chrome film with bulk properties similar to those of the commercial films. The process was tuned so that the reflectivity of the RIT film closely matched the reflectivity of the commercial films. The result was an antireflective optically dense film appropriate for photomasks for optical lithography.

1. INTRODUCTION

The field of microlithography has an important impact on the performance of microelectronic circuits. In general, a semiconductor device will perform increasingly faster with decreasing size. There is significant work being done to improve lithographic performance and print increasingly smaller features. One of the stumbling blocks to printing diffraction-limited images is flare. Flare consists of stray light in the imaging system. Reflections off of the optical elements and the mask and wafer contribute to general intensity across the exposure field. Metals are highly reflective, therefore any light that reflects off of the optical elements will reflect off of the mask surface and cause unwanted exposure on the wafer. The reflections from the top surface of the photomask can be minimized by coating with suitable antireflection layers.

2. THEORY AND DESIGN

In order for a masking film to meet the specifications required for optical microlithography, it must be optically dense at the exposure wavelength and the reflectivity must meet certain specifications. Every material has a complex index of refraction (n + ik) that defines the speed of light through the material and the rate at which light is absorbed as it passes through the film. The index of refraction is frequency dependent, that is, it changes with changing wavelength. For metallic chrome, the imaginary part of the index of refraction is relatively high, ranging between 1.66 and 3.71 for optical lithography wavelengths. The amount of light transmitted through a material is governed by the equation,

$$T = \exp(-4\pi k t/\lambda) \qquad (1)$$

where k is the complex part of the index of refraction, t is the thickness of the film, and λ is the wavelength of light. In order to build an optically dense film, a high k value is desirable as well as a thicker film. Because there are restrictions on the maximum thickness of the film, it is desirable to have as large a k value as possible. Because dielectric films have a much lower k value than metals, it makes sense that the bulk of the film should be mostly metallic. This was confirmed by the XPS data obtained on the commercial films shown in Figure 1 and 2. The bulk of the films on both Sample A and Sample B contained approximately 70-80% Chrome and 10-20% Nitrogen with trace amounts of Oxygen. The film is mostly metallic with a small portion of Chrome Nitride. It is assumed the nitride is present to assist in performing a more uniform etch rate through the film. The top surface of the commercial films contains a much higher concentration of Oxygen and a slightly higher concentration of Nitrogen. The presence of Oxygen makes the top surface of the film almost entirely dielectric. Dielectrics typically have a much lower k value and are therefore absorb less light than a metal.

The equation for Reflectance at a material interface at or near normal incidence is as follows, for an air-dielectric interface.

$$R = \left[\frac{n^*_1 - n^*_2}{n^*_1 + n^*_2} \right]^2 = \frac{(n-1)^2 + k^2}{(n+1) + k^2} \qquad (2)$$

Lowering the effective k value of the material can significantly reduce the reflectance. This means going to a less metallic surface, as the XPS data on the samples indicates. The reflectance of the top surface is a sensitive function of the complex index of refraction of the material, which in turn is a function of the atomic composition of the material and the wavelength of light.

3. PROCEDURES AND RESULTS

The XPS depth profiles of two commercial samples (Figures 1 and 2) were obtained by Evans East Company. These profiles were used to determine the bulk atomic concentrations of Chrome, Nitrogen, and Oxygen needed to provide a similar film. It was determined that the bulk of the film should be mostly Chrome with approximately 10-20% Nitrogen content. An iterative approach was taken to adjust the RF Power and Nitrogen partial pressure during the sputtering to develop a deposition process that hit the Nitrogen content target. The optimal conditions were determined to be 1200W forward RF power, 5mTorr pressure in the chamber at 20% N_2 and 80% Ar. The deposition rate was found to be approximately 36A/min.

The oxygen content of the top surface was adjusted according to the reflectance spectra of the film. The higher the oxygen content, the lower the reflectance, because of the reduced effective k value of the material. After several iterative approaches, the oxygen flow rate was determined to be 6sccm. This gave the reflectance spectra of the film that most closely matched the corresponding reflectance spectra of the commercial samples.

The following pages show examples of the reflection spectra of the RIT Cr AR Film compared to the reflection spectra of the commercial films (Figure 3). Also, the transmission spectra are plotted for the three films (Figure 4). The RIT film meets the requirements of an optical density of 3 (T < 0.001) for the desired exposure wavelengths less than 300nm.

4. CONCLUSIONS

The world of microlithography is full of many challenges. The reduction of flare in the optical system is one of the many steps taken to progress toward finer and finer resolution features. The development of antireflective absorber films for photomasks has contributed toward that end. The Chrome based AR film developed at RIT meets the performance specifications for a binary photomask film.

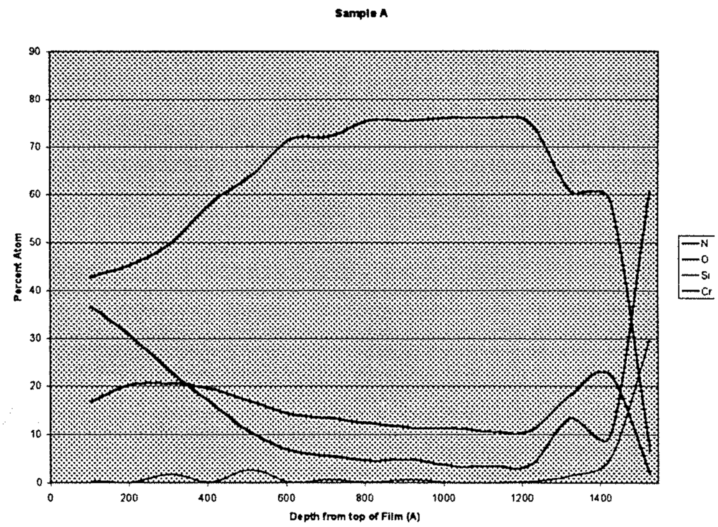

Figure 1. XPS Depth Profiles of Sample A

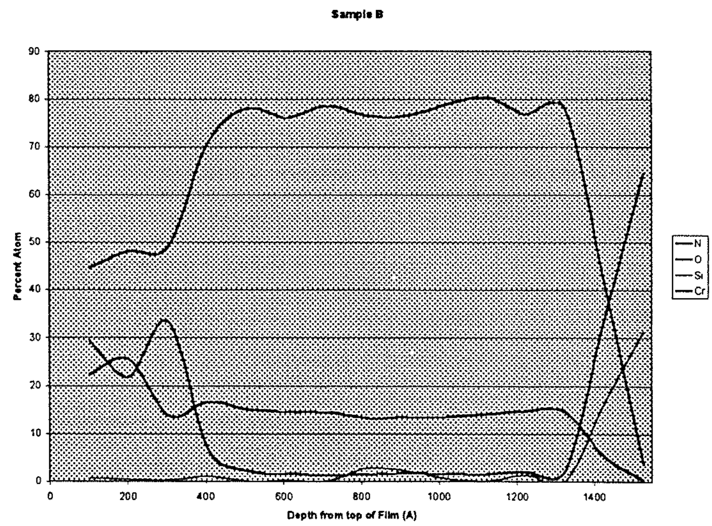

Figure 2. XPS Depth Profiles of Sample B

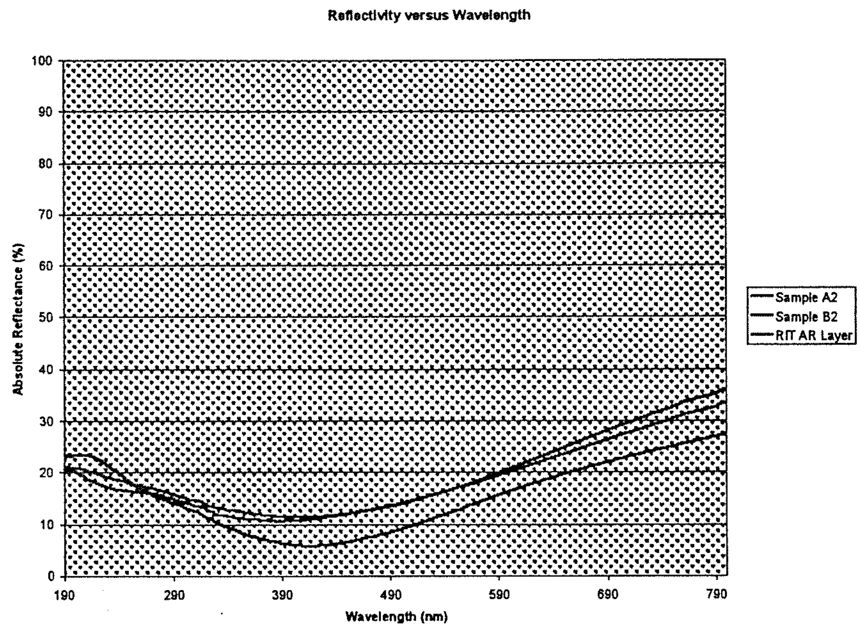

Figure 3: Comparison of Reflectance Spectra

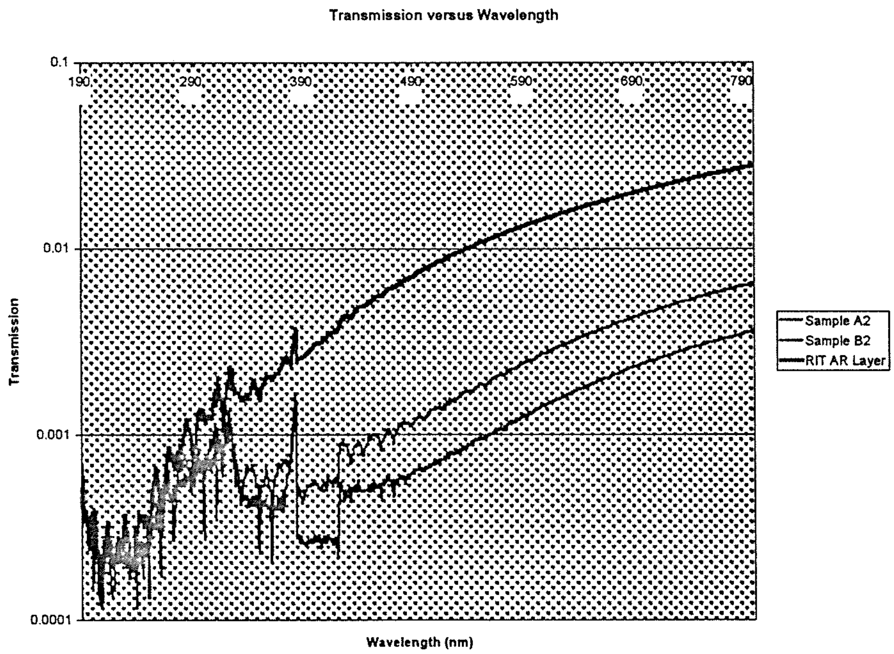

Figure 4: Comparison of Transmission Spectra