Design and Fabrication of Polarization Filter Implementing a Wire Grid Array

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Abstract-- For decades optical lithography has continually been extended past the conceived limitations of the technology. By optimizing photoresist performance and stepper settings it is possible to image features smaller then the wavelength of light being used to image. This ability allows structures to be designed such that the optical properties of the material change from what would occur at larger scales. One such structure is the wire grid array consisting of parallel metal lines on a quartz substrate. A wire grid array with a period smaller then the wavelength of incident radiation acts as a polarizer. The incident field perpendicular to the metal wires, transverse magnetic (T_M or P) is maximized. The incident field parallel to the metal wires, transverse electric (T_E or S), is minimized. A polarization filter implementing a wire grid array is demonstrated using i-line lithography.

1. INTRODUCTION

Advances in photoresist performance and the use of high numerical aperture (NA) lenses has allowed optical lithography to image features smaller then the wavelength of light being used to image. This ability allows structures to be designed so the optical properties of the materials change from what would occur at larger scales. The use of an array a parallel conducting wires was initially used by Hertz in the late 19th century to test the newly discovered radio wave. Further enhancements of the wire grid array, generally in the form of fine parallel conductors on a transparent substrate, have been limited to wavelengths in the infrared and microwave range. Wire grid arrays can now be fabricated for the visible and ultraviolet spectrums by using semiconductor process technology. This project intends to optimize the polarization effect of wavelengths in the near visible and infrared spectrums by fabricating a wire grid array on a quartz wafer.

2. THEORY

Wire grid arrays have long been known to act as a polarizer when the wavelength of incident radiation is sufficiently longer then the period of the parallel metal wires. These devices are composed of an array of parallel metal wires on a transparent dielectric substrate. A cross-sectional diagram is shown in Figure-1. The electric field of the incident radiation can be resolved into two

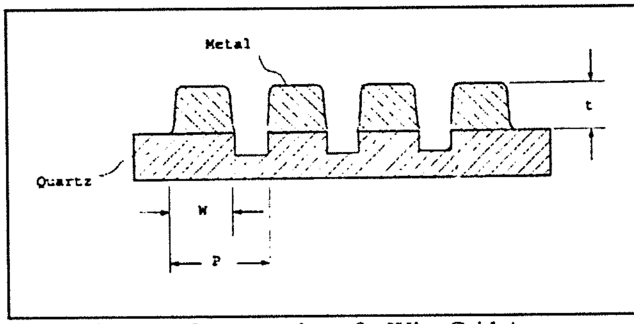

Figure-1 Cross-section of a Wire Grid Array

orthogonal components, one parallel to the wires (T_E or S) and one perpendicular (T_M or P). The field component parallel to the wires will drive conduction electrons along the axis of the wires generating a current. These electrons in turn collide with lattice atoms imparting energy to them. The energy is thus transferred from the field to the grid. Little or no transmission of this component occurs due to reflection caused by the conduction. Since the wavelength of the incident light is much larger then the width of the wires, no conduction is induced for the component perpendicular to the wires. For this reason the P-type incident radiation imparts its energy on the device as if it were a dielectric. Thus the field component in the perpendicular direction travels unaltered through the grid. High transmission is realized from the perpendicular component.

3. PROCEDURE

The project began with the layout of the grid array using Mentor Graphics IC layout software. It was decided that two grids of different period values would be used for each die. Grid arrays with period values of 600nm and 700nm were designed having wires spaced at a 1:1 duty ratio. These period values were chosen because they would push the resist processing capabilities of the laboratory equipment and would theoretically cause

polarization in the wavelength range of the ellipsometer to be used for analysis. Each wire grid array was sized to 5mm x 5mm square at the wafer level. This size wire grid array on the wafer would allow for accurate alignment of the incident radiation. A depth monitor was added at the corners of each grid array. This structure allows for the measurement of the metal thickness using a profilometer. The layout for the wire grid array was then used to make a 5" binary photomask using a MEBES3 e-beam mask writing tool.

Using the photomask dimensions a stepper job was created for the Canon FPA-2000 i1. The job contained a 13 row by 9 column array of die separated by a 1mm street. Since the process contained only one level of lithography, no alignment parameters were set-up.

Chromium metal was then deposited on the quartz wafers using a Perkin Elmer sputter tool. Sputter parameters are listed below in Table-1. Post processing profilometer measurements of the deposited chromium metal show an average thickness of 320 .

Table-1

Parameter	Value
Base Pressure	6 mTorr
Target Bias	1800 DC volts
Deposition Time	4 minutes
Power	1000 Watts
Table rotation	2 RPM

The next step involved thinning the photoresist to be used for lithography. Shipley 812 positive photoresist and MicroChem positive photoresist thinner were mixed at a ratio of 55% photoresist to 45% thinner. The added solvent would allow for a decrease in photoresist thickness after its application.

The wafers were then placed on an SSI wafer track for a 140°C dehydration bake for 60 seconds followed by a HMDS vapor prime. Using a wafer spinner, resist was then applied at 3000 RPM for 30 seconds to the wafers. The wafers were then pre-baked at 90°C for 60 seconds prior to exposure. Using a Nanospec thin film thickness measurement tool, an average resist thickness of 3100 was found.

Exposure of the wire grid array pattern was done using the Canon i-line stepper with the previously mentioned job. The job was run as a focus-exposure matrix with focus varying by column and exposure varying by row. After exposure the wafers were post exposure baked at 110°C for 60 seconds.

Shipley CD-26 developer concentration was reduced with the addition of DI water. The solution was combined at 2.8:1 developer to DI water. Exposed wafers were developed for one minute 30 seconds in an immersion bath. Following development the wafers were then hard baked at 110°C for one minute.

Cyantek CR9S chromium etchant with surfactant was used to etch the chromium metal after patterning. This process was done in an immersion bath for 40 seconds at room temperature. The wafers were then rinsed in DI water. Resist was removed using acetone instead of standard plasma ashing. The fragileness of the quartz wafers warranted caution during wafer handling.

4. RESULTS

Wafers were initially inspected using an optical microscope. One of the quartz wafers yielded six fully patterned 700nm period wire grid arrays out of 117 die on the wafer. Only partial die of 600nm period wire grid arrays resolved. A large portion of these grids were composed of non-etched chrome. Figure-2 shows an instance of a 600nm period wire grid array not fully resolving and a completely resolved 700nm period wire grid array

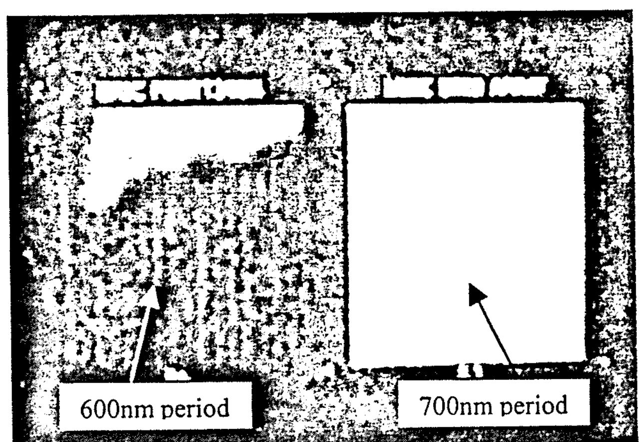

Figure-2 Resolved and Un-resolved Wire Grid Arrays

Line width measurements were completed using a Philips scanning electron micrograph (SEM). During this analysis it was observed that the uniformity of the wires was excellent. Wire widths of 360nm and space widths of 340nm were found. The actual SEM image of a 700nm period wire grid array is shown in Figure-3. The SEM measurement bar at the bottom of Figure-3 is 1.0µm long.

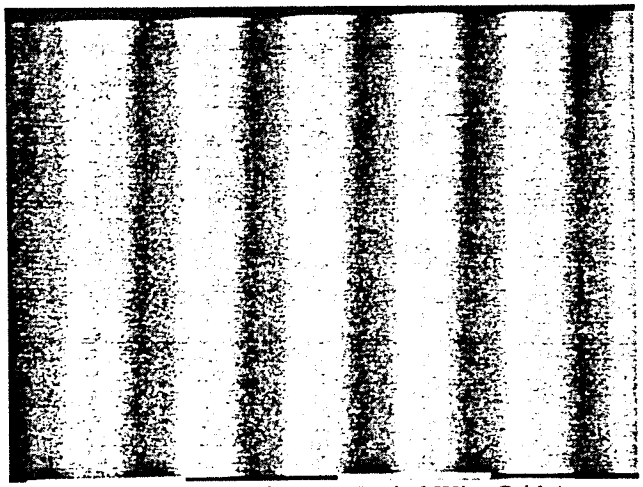

Figure-3 SEM Image of 700nm Period Wire Grid Array

Through the use of thinned photoresist and diluted developer, lithography was optimized for the 350nm wires. Process optimization can be represented by the k_1 factor in the commonly used Rayleigh equation:

$$R = \frac{k_1 \lambda}{NA}$$

where R is resolution, λ is the wavelength used to image, and NA is the numerical aperture of the imaging system. The Canon FPA-2000 i1 stepper uses a wavelength of 365nm and has a 0.52NA lens system. The k_1 factor for the process used here calculates to be 0.48, significantly lower then the 0.7 k_1 factor for the standard resist process used in the laboratory.

A uniformly resolved 700nm period wire grid array was then analyzed using a Woollum WVASE Ellipsometer. Through wavelength transmission measurements were made from 350nm to 1700nm. Polarization data for the S and P polarization states were collected during each measurement scan. Transmission measurements were taken at a zero degree incident angle. Results from these measurements are shown in Figure-4. At a wavelength equal to the period of the wires the wire grid array did not polarize the incident radiation. The six percent difference in transmission between P and S type polarization states is insignificant with regard to the scope of this experiment. At wavelengths greater then 1000nm it is shown that the wire grid array significantly changes the transmission characteristics of the incident radiation. At twice the period of the wires, incident radiation is polarized more towards the P state. The equation below relates the transmission of each state to the efficiency of the wire grid array as a polarizer:

$$Efficiency = \frac{TP - TS}{TP + TS}$$

Ideally a wire grid array should polarize incident radiation with 100% efficiency. The wire grid array fabricated in this experiment provides 22% efficiency after wavelengths greater then twice the period of the wires. Greatly influencing this less then ideal efficiency is the high transmission of the S state. The most reasonable explanation for this occurring is that the chromium metal was too thin. At longer wavelengths most materials start to become more transparent. In this experiment the chromium metal thickness was limited by the wet chemistry etching process and the resulting undercutting of the metal.

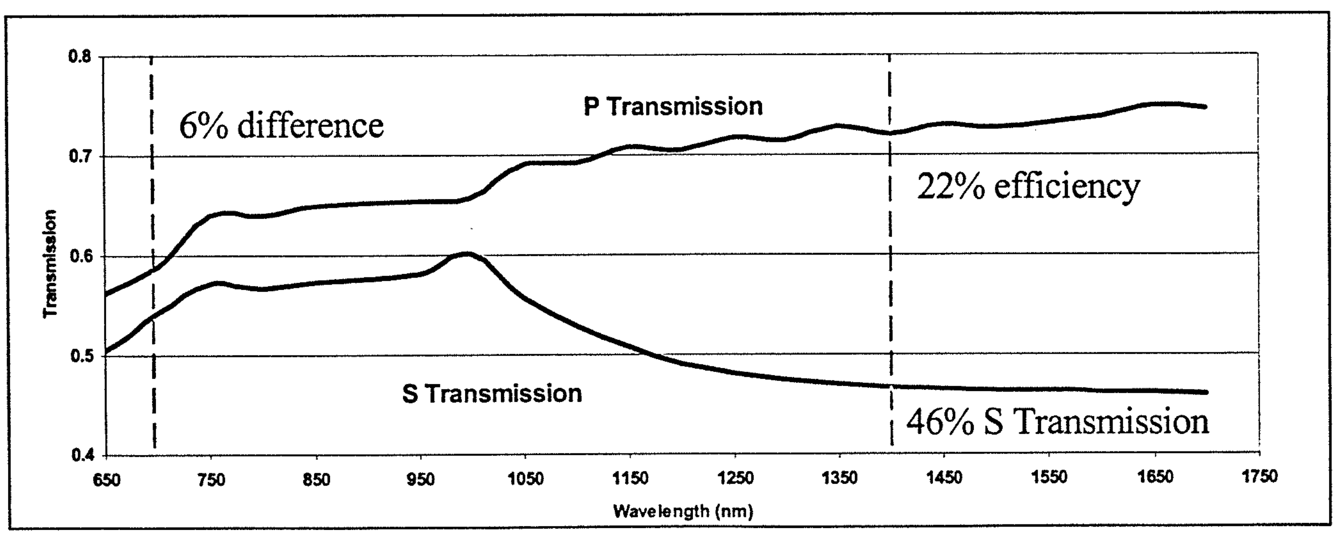

Figure-4 Transmission versus wavelength results obtained from spectroscopic ellipsometry for a 700nm wire grid array.

Another factor which may limit the efficiency of the wire grid array is the profile of the wires. Use of wet chemistry etching results in isotropic etch profiles. The sidewalls of the etched metal become rounded. Ideally the metal wires should have a 90° sidewall as shown previously Figure-1. The impact of this is that the edges of the wire are thinner then the middle of the wire. As stated previously, the transmission of incident radiation increases with thinner metal.

5. CONCLUSION

A polarization filter implementing a wire grid array was successfully designed and fabricated. Resist process optimization allowed the imaging of sub-wavelength features using i-line lithography. A chromium metal on quartz wire grid array with 360nm wires at a 700nm pitch was resolved. Although non-ideal, the wire grid array did provide 22% efficiency at wavelengths twice the pitch of the wires.

Further process refinement would increase the efficiency of the polarization filter. Increased metal wire thickness would drive S type polarization towards zero transmission. Metal capable plasma etching would be required for this processing. Pushing the k1 factor lower would allow imaging of smaller wires at a smaller pitch. Polarization would then be induced at lower wavelengths.

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