Characterization of an organic, wet develop, broadband, experimental back anti-reflective coating (BARC)

Robert Kress
Microelectronic Engineering Department
Rochester Institute of Technology
May 1998

Abstract--The objective of this project is to characterize Brewer Science EXP97011 experimental broadband back anti-reflective coating (BARC). This BARC was designed to function at both i-line (365 nm) and g-line (436 nm). The focus of this experiment is to incorporate the BARC process into existing lithography processes at RIT. A "Poor Man's" DRM was performed on both the BARC as well as Shipley 812 photoresist to determine optimum develop time as well as optimum bake temperature for the BARC.

Once the optimum conditions were found, several wafers were processes through 1st level lithography using the BARC on a polysilicon layer and subsequently etched. This was done to observe any effects undercutting of the BARC during develop would have on etched features. SEM analysis will be performed to analyze undercutting as well as standing wave effects in the photoresist caused by reflections off the polysilicon during exposure.

The optimum bake temperature for the BARC was found to be 160^{O} C for 45 seconds with an initial bake of 100^{O} C for 60 seconds. At this temperature, the develop rate was found to be approximately 30 nm/sec. The optimum development time for approximately 900 angstroms of BARC with 1.2 microns of photoresist was found to be 40 seconds using MF-351 developer. The optimum exposure energy was found to be 105 mJ/cm^2. SEM analysis showed a significant undercutting effect with a slight over-development of the BARC. This indications a need to tightly control the development parameters. Standing waves were not observed due to a "pitting" effect on the sidewall resist lines.

INTRODUCTION

As design rules get smaller, the need to minimize reflections during exposure becomes increasingly more important. Reflections off the substrate can cause standing waves effects in the sidewalls. This has the effect of possible scumming of the resist features which leads to greater problems during subsequent steps such as etch or implant. Another concern is the notching effect which results when reflections cause exposure in unwanted areas. This creates "notches" in the features upon develop. With smaller features, this notching effect could result in a complete break in the resist line.

The use of a back anti-reflective coating (BARC) enables the reflections to be minimized and thus the standing wave and notching effects are reduced.

While the use of a BARC results in improved features, it also results in lower throughput due to the fact that additional process steps are required. 2 additional bake steps for the BARC are required as well as additional exposure energy. The two additional bakes are performed prior to resist and are similar to a soft bake for resist. For this experiment, the 2nd BARC bake is the critical bake because it is this bake that sets the development rate.

A BARC must have certain necessary characteristics. It must absorb strongly at the exposure wavelength to ensure that reflection does not reach the photoresist. It must also develop cleanly in the exposed areas to ensure a good pattern transfer through the BARC to the underlying layer. This leads into the use of a development rate monitor technique to determine the optimum development rate and bake temperature for the BARC.

A "Poor Man's" DRM was used for this project to determine optimum processing conditions. The technique is referred to as "Poor Man's" due to the fact that very little automation is involved. After the wafers are coated and processes, they are hand developed at 10 second intervals and subsequently measured after each iteration. This data is then entered into ProDRM, which calculates the dissolution rates for the material. For the BARC, various bake temperatures were used

while various exposure energies were used to determine dissolution rates for the photoresist.

PROCESS

1000 angstroms of oxide was grown on 10 silicon wafers using Bruce Furnace tube #4. This was done to serve as an etch stop later in the process. An LPCVD polysilicon run was done on the wafers to obtain approximately 6000 angstroms of poly on the wafers. In addition, three bare silicon wafers were placed aside in order to be used later in the project.

The specific BARC used for this project was Brewer Science EXP97011. The BARC was hand coated on a spinner for 30 seconds at 1500 rpm. This gave an approximate BARC thickness of 1.8 µm. After the wafers were coated, two separate bakes were performed on them. The first bake was at 100° C for 60 seconds, which was standard on all wafers. The second bake, which is the critical bake in determining dissolution rate, was varied in order to determine an optimum temperature. This bake was varied from 155° - 185° C in steps of 5 degrees. One wafer was run at each temperature for 45 seconds. A simulated PEB was performed on the wafers at 115° C for 45 seconds.

Once the bakes had been completed, the wafers were developed in Shipley MF-351 developer mixed at a 5.45:1 ratio with H_2O. A wafer was placed in this solution at 10-second intervals, with the thickness of the BARC being measured between each interval. All BARC measurements were taken on an automated ellipsometer. These development steps were continued until the BARC had cleared from the wafer.

After all of the conditions for the BARC were completed, the wafers were placed in the asher in order to remove any residual traces of the BARC. The wafers were then cleaned and wafer 5 was coated with Shipley 812 photoresist using RIT's standard resist program on the WaferTrac. The approximate thickness of the resist was 1.2 µm. An exposure matrix was then run on the wafer with varying exposures from 0 to 124.2 mJ/cm^2. A postbake of 115° C. for 45 seconds was performed and the wafer was developed in a manner similar to the BARC using Shipley MF-351 developer. 36 exposures were measured across the matrix, with a Nanospec being used to measure resist thickness between each 10 second interval. This process was continued until several of the exposures had cleared of resist.

Once the development data for the BARC and the photoresist was obtained, this data was entered into ProDRM, which calculated the development rates for the materials. ProDRM results can be seen in figures 1 and 2.

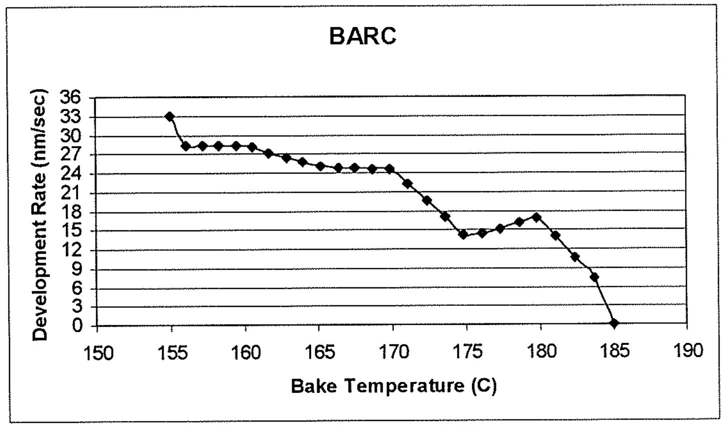

Figure 1: DRM results for EXP97011 BARC

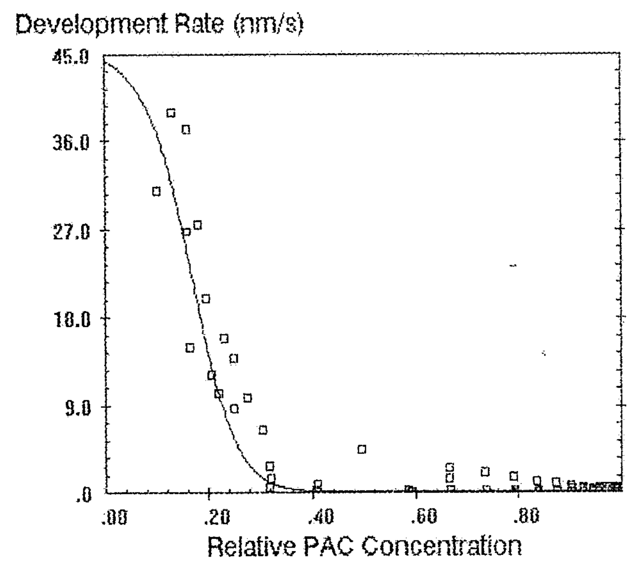

Figure 2: DRM results for Shipley 812 photoresist

By analyzing the two charts, it was determined that the optimum bake temperature for the BARC was 160° C with a total develop time of 40 seconds for the BARC/photoresist stack. Using these conditions, an exposure matrix was performed which determined the optimum exposure value to be 105 mJ/cm^2. The BARC was coated at 3000 rpm for 30 seconds, which gave an approximate thickness of 900 angstroms. This value was obtained my modeling the BARC in Prolith. The thickness of the resist was 1.2 µm

Wafers 5,8,6, and 10 were then processed using the optimum conditions. All exposures were performed on the GCA g-line stepper with RIT ETM reticle. A polysilicon etch was performed on wafers

5,8, and 6 in order to observe undercutting effects of the BARC. Wafer 6 was overdeveloped for 5 seconds to enhance this effect. Wafer 10 was not etched in order to examine standing wave effects and sidewall profiles. Wafer 1 was process with only photoresist using RIT's standard process to compare standing wave effects with wafer 10.

The wafers were then sputtered with approximately 150 angstroms of gold and analyzed using a SEM at the University of Rochester. 4 μm lines were examined in an attempt to observe undercutting effects as well as comparisons between wafers with and without the BARC.

RESULTS:

Using the "Poor Man's" DRM technique, optimum bake conditions were obtained for the BARC as well as development time using Shipley MF-351 developer for the BARC/photoresist stack. Using 1.2 μm of resist with 900 angstroms of BARC, these conditions were an exposure of 105 mJ/cm^2, two pre-exposure BARC bakes of 100 and 160° C for 60 and 45 seconds respectively, and a total develop time of 40 seconds.

Severe undercutting effects were observed with the wafer with a 5 seconds overdevelop and subsequent polysilicon etch (wafer 6, figure 3). This indicates the need for a tight process control to ensure useable features.

Wafer 10, which was processed using optimum conditions, showed no noticeable undercutting of the BARC upon develop (figure 4). After the polysilicon etch, the result was very minimal undercutting effects. These results seem to indicate that the DRM was a success in obtaining optimum process conditions for the BARC at g-line.

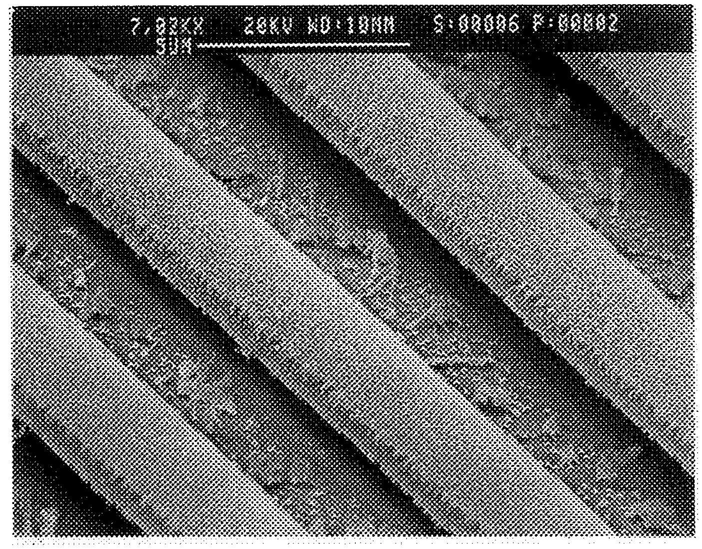

Figure 3: Undercutting effects with slight overdevelop of BARC and poly etch on 4 mm lines

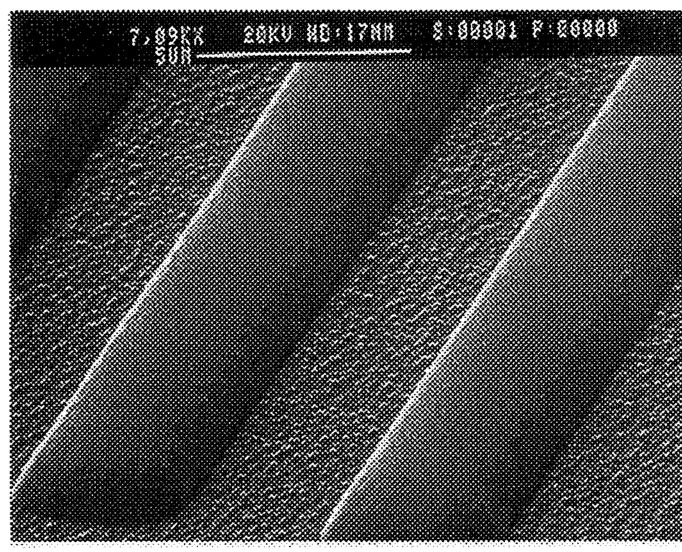

Figure 4: Post-exposure of wafer with BARC coating but no poly etch (4 μm lines)

Standing wave effects were not observed in any of the features due to a "pitting" effect, as seen in figure 5. The origin of this is unknown, but seems to be reduced when the BARC is used.

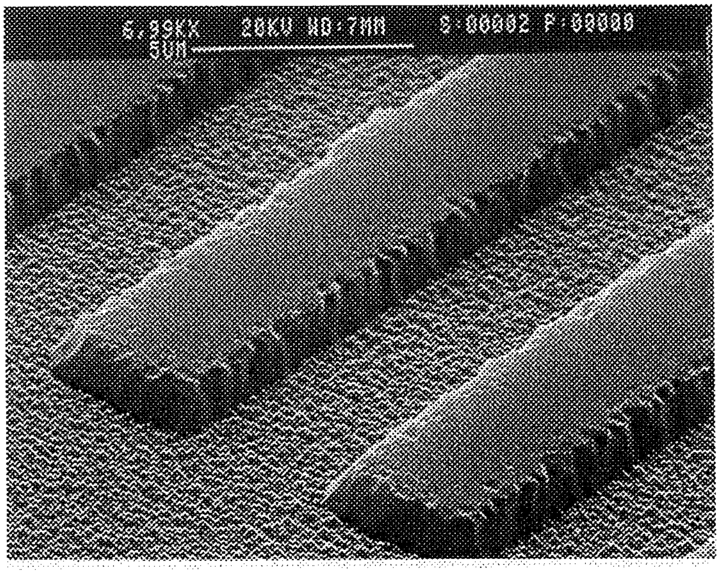

Figure 5: 4 μm lines after develop with no BARC coating

CONCLUSIONS

The optimum conditions for this BARC at g-line are a 100, 160^{O} C bake process, as well as a 40 second develop time for the BARC/photoresist stack. An optimized exposure dose of 150 mJ/cm^2 was found for 1.2 μm of photoresist and 900 angstroms of BARC.

The isotropic development nature of the BARC is a large concern when processing. If the development conditions are not tightly controlled, undercutting effects may be so severe that the features become useless.

Since this BARC was designed to funciton at both g-line as well as i-line, future work would most definitely involve optiimiztion at 365 nm. Other experimental work also could be done using an underlying aluminum layer instead of polysilicon. An attempt could also be made to find the origin of the "pitting" effect in an attempt to compare standing waves in features both with and without the BARC.