The Design of an Inorganic BARC

Andrew Veter
Microelectronic Engineering
Rochester Institute of Technology
Rochester, NY 14623

Abstract — **A methodology was arrived at for the design of an inorganic bottom antireflective coating (BARC). The design methodology consisted of four parts. First, a material compatible with IC processing was chosen. Second, simulation was performed to determine the optimum optical properties of the material, where the materials extinction coefficient, and film thickness were varied to produce zero substrate reflectivity. Third, the stochiometry of the material was varied through experimentation to produce a film with the index of refraction and extinction coefficient as close as possible to the simulation results. Fourth, the results of step three were used in simulation to re-determine the film thickness required to produce zero reflectivity at the substrate. The methodology was implemented and a SixNy BARC was designed for RIT's G-Line (436nm) process. The applicability of the design method to any exposure wavelength is demonstrated by designing an I-Line BARC concurrently. The film conformality of organic and inorganic BARCs were compared.**

I. INTRODUCTION

As the semiconductor industry continues its drive towards higher and higher packing densities, manufacturers are continuously confronted with new and interesting challenges. These challenges have presented themselves not as theoretical barriers or physical limitations, but as high volume manufacturing issues. For instance, it has been demonstrated that devices on the order of 50nm can be created under laboratory conditions, but the feasibility of manufacturing these devices cost effectively and in high volumes has yet to be determined.

One area that has drawn significant attention in recent years is photolithography. Although exotic technologies exist to define patterns well into the deep sub-micrometer regime, the cost associated with these advanced technologies, due to capital investment and throughput issues, is staggering. It is no wonder then that a large amount of resource has been expended in extending the lifetime of conventional lithographic technologies.

One common way of doing this is through the use of a Bottom Anti-Reflective Coating (BARC).

Currently, the most commonly employed lithographic strategies involve the projection of electromagnetic radiation onto photosensitive materials, using step and repeat systems. These systems, called steppers, are tailored to expose photoresists at the specific wavelengths to which they are sensitive. A BARC is a thin layer of some reflection suppressing material deposited between a photoresist and its underlying layer (substrate). It is designed to absorb light that penetrates through the resist and is usually tailored to the specific wavelength of the exposing radiation. It is important that any penetrating light be absorbed because a certain percentage of light incident on an interface or topographic feature will be reflected. This is extremely undesirable, especially when imaging critical layers such as polysilicon gates, due to its severe impact on pattern resolution.

BARCs have been used to enhance pattern resolution for many years in the IC industry. Traditionally, BARCs have been organic compositions that are generally easy to design, easy to apply, and can eliminate reflections entirely. Unfortunately, as device dimensions are scaled into the deep sub-micrometer regime, these types of BARCs can no longer perform to the increasingly stringent requirements placed on them. This is mostly due to the fact that organic BARCs are applied via a spin-coat method that causes variation in the films' thickness across a wafer. Currently, the best spin-coat processes boast variations of around ±50Å. Unfortunately, a difference of 50 Å can increase reflectivity by several percent and it is commonly understood that reflectivity must remain below 1% for linewidth control, especially when imaging critical layers such as at poly gate definition.

It is because of these thickness variations that other solutions are becoming the focus of considerable attention, the most promising of which are inorganic BARCs. Inorganic BARCs differ from organic BARCs in that they can be sputtered or CVD deposited onto a wafer, both of which are conformal depositions. This eliminates the thickness variation effects of organic BARCs. In general, inorganic BARCs are also cleaner films and in some cases can be left behind after processing. Although

they suffer from longer throughput times and require more expensive deposition equipment, they are more than adequate as a replacement for conventional organic BARCS in the deep sub-micrometer regime.

This report details the design of an inorganic BARC. The design is shown to be a straightforward exercise using the Prolith® lithography simulator, an ellipsometer with WVASE32 interpretive software, a PerkinElmer spetrophotometer, and a PerkinElmer 2400 Sputerer. Although the process is developed for G-line (436nm) technology, an i-line (365nm) equivalent is developed to demonstrate the versatility of this design process. The conformality of films are qualitatively compared between organic and inorganic compositions.

II. THEORY

Reflections from the resist/substrate interface can have multiple consequences, including linewidth variation and notched or uneven profiles. Figure 1 demonstrates the various mechanisms by which reflections occur.

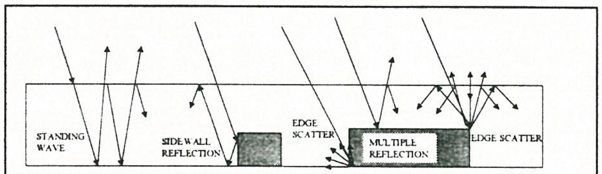

Figure 1: Film and Topographic Reflections

The main reflection phenomenon of interest is the production of standing waves in the photoresist layer. These standing waves occur as reflected light interferes either constructively or destructively with incoming radiation, causing a periodic intensity distribution within the film. During exposure of the photoresist, the lateral intensity variations in a projected image must compete with the vertical intensity standing wave variation. During subsequent development of the exposed photoresist film, the development action rapidly proceeds laterally along constructive interference nodes, while it is slowly proceeding vertically through the destructive interference nodes.[i] Thus, standing waves will have an effect on edge profile and linewidths. Figure 2 shows a resist line that was produced by disabling the post-exposure bake in RIT's standard lithography process. The standing wave intensity profile is clearly discernable along the lines' sidewalls.

The problems particularly associated with imaging on *topographical* structures include resist thickness variations due to the spin-coat process over steps, standing wave interference, and scattered light reflections, all of which cause exposure variations within the resist film. BARC under a resist film eliminates the discordant effects of resist thickness variations and reflections.[1]

Figure 3 shows a resist line that was processed identically to the one in Figure 2, except that it was patterned on top of an organic BARC, Brewer® XLT. Notice the complete lack of a standing wave profile. In general, the addition of a BARC facilitates the suppression of substrate reflections which leads to improved resolution. Also, a focal depth improvement and an increase in aberration tolerance will occur.

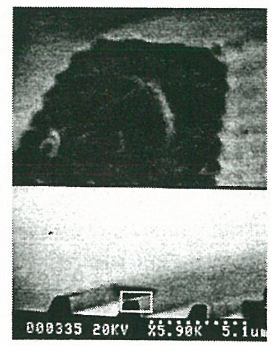

Figure 2: Standing Wave

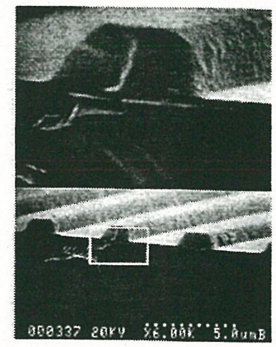

Figure 3: Resist Line Over BARC

The design of a BARC considers three basic parameters. These are the index of refraction, the extinction coefficient, and the film's thickness.

The conventional optical equation;

$$n = \frac{C}{V} \qquad (1)$$

is a real expression. When considering a materials property the complex quality described by its absorbance must also be taken into account. The complex index of refraction is;

$$n^* = n - ik \qquad (2)$$

where k is the materials extinction coefficient. The extinction coefficient is determined from a materials absorbance (α) as;

$$\alpha = -LN(Trans.) = \frac{4\pi k}{\lambda} \qquad (3)$$

Therefore, the common equation for reflectivity is modified and can be expressed as;

$$R = \frac{(n_1 - n_2)^2 + k^2}{(n_1 + n_2)^2 + k^2} \qquad (4)$$

Where n1 is the index of refraction for a photoresist and n2 is the index of refraction for an underlying film. [ii]

A BARC is designed so that any light penetrating through the resist is transmitted into the BARC where it is completely absorbed. The conundrum is that for zero reflectance at the resist/BARC interface, the extinction coefficient must be zero. Obviously, a balance must be struck. `Conventional spin-on BARCs utilize very low extinction coefficients on the order of .25 and rely on the relative thickness of the film (~2000Å) to completely attenuate transmitted light. The design of an inorganic BARC, however, is complicated by the fact that their thicknesses are in the 200Å to 900Å range. Another method of ensuring a minimum reflectance, other than attenuation, must be achieved. For an inorganic, or as it is often described, dielectric BARC, the other method is total phase shift cancellation[iii]. Any light that enters the BARC must be reflected with equal amplitude but opposite phase from the BARC/substrate interface. Therefore, a properly designed inorganic BARC requires that a balance is achieved between the index of refraction (n), the extinction coefficient (k), and the film thickness (t).

Obviously, for phase cancellation the uniformity of the thin film thickness is paramount. Figure four and five demonstrate the conformality of a spin-coat BARC and a sputtered BARC respectively.

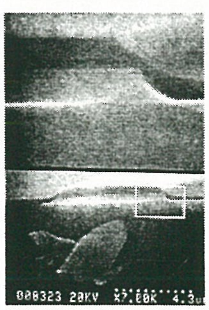

Figure 4: Brewer XLT Over SiO2

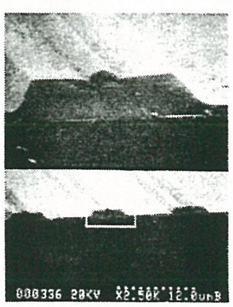

Figure 5: Sputtered SiNx Over SiO2

III. DESIGN

The design of an inorganic BARC is a very straightforward procedure once the theory is understood. The design developed in this report consists of four parts.

First, a material compatible with IC processing is chosen. The material of choice for this experiment was an SixNy composition. Si3N4 is the common film used in LOCOS isolation and deposited films of these types are fairly well known. Further, these films are easily formed by simply varying the nitrogen flow of a silicon sputterer, such as the PE2400 of this report. Second, simulation is performed to determine the optimum optical properties of the material, where the materials extinction coefficient and film thickness are varied to produce zero substrate reflectivity. Varying all three factors would unduly complicate the simulation and n is initially assumed to be invariant at 2.1. This is allowable, as a wide variety of n-k combinations will achieve the desired result of 0 reflectivity, the only affect being a change in the appropriate film thickness range. Therefore, the initial focus is on obtaining an acceptable extinction coefficient. The simulator of choice at RIT is Prolith® by Chris Mack. Figure 6 and 7 were generated from the Prolith® simulator.

Third, the stochiometry of the material is varied through experimentation to produce a film with an extinction coefficient within the acceptable range determined through simulation. The only factor varied for this design was the nitrogen flow during the silicon sputter deposition. Evaluation of the films optical characteristics was performed using the WVASE® software, which is an optical data analysis tool used in conjunction with any optical data-producing tool. In this case, an ellipsometer was used as the data producer. When using an ellipsometer, the experimental data obtained must be fit to a model, with the fit parameters providing the desired information[iv]. WVASE® is a particularly powerful tool in extracting optical properties.

Fourth, the results of step three are used in simulation to re-determine the film thickness required to produce zero reflectivity at the substrate.

IV. DATA AND RESULTS

The initial simulation showed that there was a fairly large range of acceptable extinction coefficients. The range for both G and I line is taken to be ~.3 to .8. Although extinction coefficients below .3 are useable, the film thickness necessary quickly becomes very large. The .3 value is taken relatively arbitrarily. For a specific process, acceptable film thickness ranges should be well known and explicit.

Experimentation was performed by sputtering silicon and varying the nitrogen gas flow. Data was

extracted using the WVASE32 and the measurements showing the least error are shown in Table 1. These films also show extinction coefficients within the acceptable .3 to .8 range.

EXPERIMENTAL DATA EXTRACTION		
Sample	VET2	VET5
Wavelength	365nm	436nm
Argon	28sccm	28sccm
Nitrogen	3.0sccm	3.5sccm
Power	500W	500W
n	2.619	2.751
k	0.647	0.344
t (Ang.)	1514.6	1296.8

Table 1: Experimental Optical Constants

It is important to note that the sputter conditions between the two samples cannot be compared because the sputterer underwent extensive repair between runs.

Once the optical parameters were extracted, the values were used in simulation to re-determine the film thickness required to produce zero reflectivity at the substrate. Figure 6 and 7 are the results of that simulation.

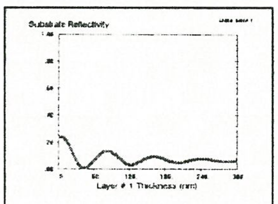

Figure 6: G-Line

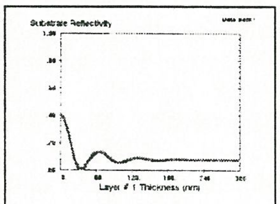

Figure 7: I-Line

The simulation demonstrates essentially zero substrate reflectivity at discrete film thicknesses. Table 2 contains these values and the range in which the substrate reflectivities remain below 1%.

BARC THICKNESS RANGE (For Zero Substrate Reflectivity)	
G-Line (Angstroms)	I-Line (Angstroms)
510 - 370	450 - 290

Table 2: BARC Thickness Range

IV. CONCLUSION

The design of inorganic BARC was shown to be a straightforward exercise. Four steps were proposed for the design, including the selection of an appropriate material, initial simulation to determine the range of usable extinction coefficients, experimentation, and finally re-simulation using optical parameters extracted from experimentation. Both a G-Line and I-line BARC of SixNy composition were designed using these steps.

V. ACKNOWLEDGEMENT

The author wishes to acknowledge Dr. Bruce Smith for his technical guidance and Dr. Santosh Kurinec for her support.

[i] RIT Document Title ARC.MEM, VAXD, Account KHHEMC, Directory EMCR575

[ii] Smith, Bruce W., Principles of Microlithography

[iii] Bencher, Ngai, Roman, Lian, Vuong, "Dielectric antireflective coatings for DUV lithography" Solid State Technology, p.109, March 1997

[iv] J. A. Woollam Co., "A Short Course in Ellipsometry", Guide To Using WVASE32™

Andrew Veter received his B.S. degree from the Rochester Institute of Technology in 1997. He is currently employed by Digital Equipment Corporation in Hudson, MA, where he is a sustainment engineer in the photolithography department.