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Fundamentals in Bottom Anti-Reflective Coating Design For Its successful Integration Into i-line and DUV Manufacturing

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Biography

Paul Williams received his B.Sc. in Physics from Nottingham University in 1989 and his Ph.D. on hot electron transport in GaAs devices from University of Wales, Cardiff in 1993. Before joining Brewer Science in Europe as an Applications Engineer, he worked as a Postdoctoral Research Associate at Cavendish Laboratories, Cambridge University working on laser spectroscopy of GaAs devices. His current position at Brewer Science is the Marketing Manager for Asia.

Xie Shao received her Ph.D. in organic chemistry in University of Basel, Switzerland, followed with two years postdoctoral experience in Ciba-Geigy AG, Department of Pharmaceutical research, and one year postdoctoral in SUNY (State University of New York) at Buffalo, Department of medicinal chemistry. She joined Brewer Science in 1993 as Sr. Research Associate. Her current position is product manager responsible for DUV BARC products.

Keith Strassner received a Master Degree in Marketing from Webster University and a BS Chemistry degree from the University of Missouri-Rolla. He joined Brewer Science in 1998 as Manager of Global Marketing, ARC Division having served in a variety of marketing and business development functions in the specialty chemical industry. His current position is managing director in Chemical Unit of Brewer Science Inc.

Abstract

As manufacturing lines are moving to produce higher functionality integrated circuits [ICs], the minimum critical dimension [CD] must be reduced. There becomes a point when the CD being printed is the same as the wavelength used to define the photolithographic image. Since lithography tools have a considerable cost, IC manufacturers now routinely employ the equipment for feature sizes below the wavelength of light.

As the wavelength of light is reduced, the reflection from the substrate increases which degrades the process window. By introducing BARC technology, it is possible to extend the lifetime of these tools and expand the process window by eliminating back reflections from the substrate. This technology coupled with advanced illumination settings can yield successful lithography beyond the exposure wavelength.

1. Introduction

Previously [1] we have described the theoretical characteristics required for an anti-reflective coating. This paper will focus on the components that contribute to the reflectivity curve of the BARC. Traditionally, BARC was used on critical levels such as polysilicon gates. However, as CD specification and overlay tolerance has become tighter, BARC has been introduced successfully onto more transparent substrates. Recently, due to the advanced planarization of these layers [in an attempt to increase depth of focus], lithography engineers have to accommodate for multiple interference effects from different thickness of transparent layer within the substrate stack. This is solved with the introduction of BARC. However, as the CD becomes smaller, higher demands are expected from these materials. In addition to planar surfaces, BARC applications include CD control on advanced non-volatile technology. This can results in demanding topography. Also, BARC is increasingly used as an etch-block and poisoning barrier layer in such applications as Dual Damascene Via first and Low-k Inter Layer Dielectric applications [2,3]. As a result, BARC design now involves tailoring the rheology and molecular weight as well as the inclusion of amine blocking media. As production demands higher throughput and tighter CD control, there are three design considerations that are used to enhance the performance of BARC. These are 1) the optical

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components, 2) The etch rate of the bottom ARC and 3) removing the etch step altogether by providing printable BARC. Each of these aspects will be described in more detail and their application to lambda and sub lambda applications.

2. Materials Design

BARC compositions are required to perform three functions: (1) provide a uniform, defect-free coating over the substrate; (2) offer high absorbance at the exposure wavelength so as to reduce swing effects and reflective notching; and (3) etch faster than the photoresist.

In general, spin-on organic BARC is a liquid formulation comprised of the following main components: a polymeric binder, a light absorbing material - either attached to the polymer binder or not, and a solvent system. Polymers selected for BARC coatings must have sufficient solubility in their formulation. They should be thermally stable, have good adhesion to the substrate, be inert to the solvent in the BARC formulation and to the subsequent processing solvents, and exhibit high plasma-etch rates. The light absorbing material (chromophore) must offer high absorbance for the given wave length, high etch rate, and inertness to both BARC and subsequent processing solvents, and exhibit low or no sublimation. The solvent system must be environmentally safe, inert to the coating system, and should have a high flash point. Fig 1 illustrates general structures representing the first, second and third generation BARCs.

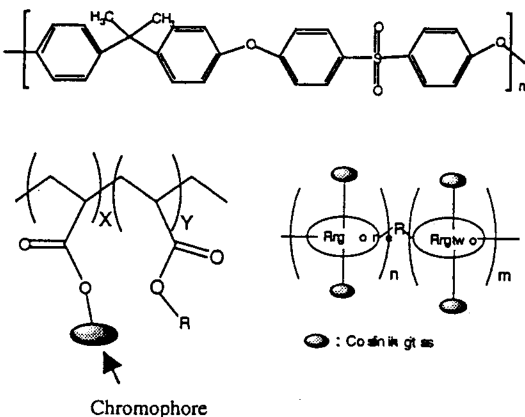

Fig.1: Schematic representation of organic BARCs

3. Optical component optimization

Current Organic BARC systems have traditionally been designed to match the real component of the refractive index [n] with the photoresist system and the excitation coefficient of on wafer [k] of the refractive index to give a low baseline reflectivity at thick BARC thickness. For example, the first generation BARCs [e.g. From Brewer Science CD3/9 and CD11] were simple chemistries which had limited absorbtion at 248nm (n=1.79, k=0.23). Resulting in a reflectivity minimum at DUV of 110nm on opaque substrate such as silicon. However, as lithography moved to 0.25μm and below, most users requested higher absorbance. As a result the second generation of BARC were designed. These were a much more complex system with optical components of n around 1.5 and k around 0.50. Recently as deep sub wavelength [0.15μm to 0.12μm patterning with 248nm exposure] the third generation of BARC has been introduced where the optimum thickness has been reduced further to accommodate for ultra-thin BARC. Here the n and k are 2.0 and 0.5 respectively. Figure 2 shows the progress in optical performance from first to third generation BARCs.

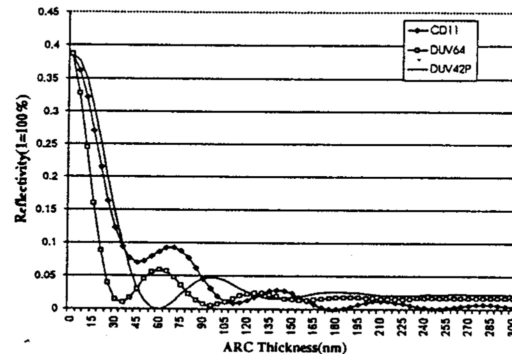

Fig. 2. Reflectivity curve of first, second and Third generation BARCon opaque substrate Showing the progress in minimizing BARC thickness

To achieve this shift in optical characteristic, a more complex chemical platform was adopted, and a schematic of an advanced BARC system is shown in Figure 3.

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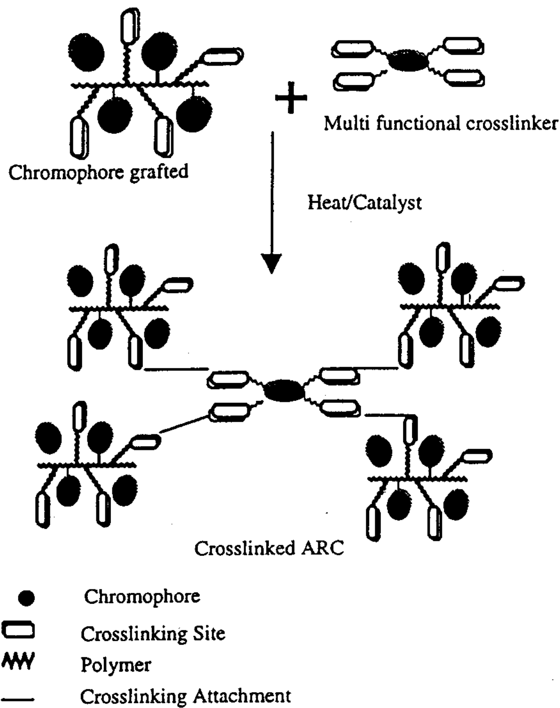

Fig. 3. Schematic representation of the components included in an advanced cross-linking BARC

In addition to minimizing the "first minimum" thickness on opaque substrates, these advanced BARCs offer substantial lithography and CD budget advantage on transparent films. Baseline reflectance can now be controlled to within 5% for standard thickness applications and in-fact a thinner BARC can now be used for reflectivity control. To facilitate this advancement, an upgraded polymer and chromophore platform has been developed. The improvement in reflectivity control with advanced optical characteristics is shown in Figure 4.

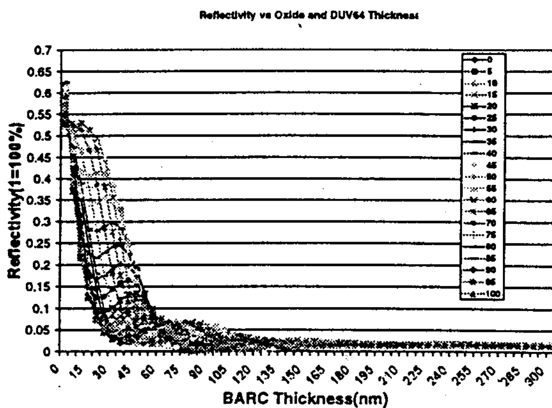

Fig. 4. The effect of optimizing n and k for transparent substrates

Besides the absolute thickness of BARC needed, the patterning of the BARC is another consideration. We shall now discuss advanced BARC design which has been optimized for two patterning considerations. A fast baseline etch rate in "dry" plasma processes; and tunable dissolution rate of a printable BARC in a standard develop or "wet" patterning BARC.

4. Etch rate optimization

If a dry process is to be used, for a given BARC thickness, as a general rule, high BARC etch rates are required for throughput considerations. In some aspects of integration, such as gap fill Via-First applications in Dual Damascene interconnect, the BARCs are used as etch-block media [4].

For typical BARC open etch on Polysilicon, halogenated and oxygen-rich plasma gas chemistries have been used. These have two advantages. Firstly the Oxygen gas will "ash" the organic BARC [essentially burning the organic material], secondly, it also has a very high selectivity to the underlying polysilicon, thus avoiding the risk of aggressive pitting or damage to the substrate. For advanced patterning, the photoresist thickness is reduced and a BARC process is established [5]. Since the resist mask is now thinner, a faster etch BARC is required [6]. Baseline etch rate can be modified in a number of ways, first, by changing the gas chemistry. If the Oxygen to halogenated gas ratio is increased, a faster etch rate is observed, however, the resist loss is also increased [7]. The baseline etch rate and selectivity to photoresist can also be increased by UV cure of the film stack. This has two functions, firstly to further cross-link the photoresist and secondly it also acts to break down the BARC [8]. The third method is to change the design of the BARC. By modifying the backbone polymer and chromophore ratio of aliphatic and aromatic groups different etch rates for a given gas chemistry are achieved.

Fig 5 showed etch rate of BARC products in Fig 1 in different etch gasses.

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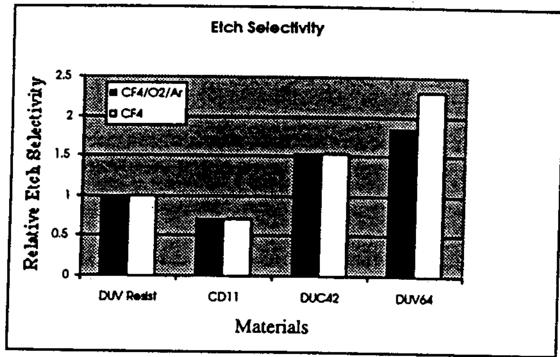

Fig. 5. Etch selectivity of 1st, 2nd and 3rd generation BARCs

Clearly, if throughput and cost of ownership were the only considerations, no BARC etch is the ideal solution. To account for this Brewer Science designed a series of BARCs which is soluble in aqueous developer to meet customers different needs. This is so called wet developable BARC

5. Wet developable BARCs

Wet developable BARCs were first introduced by Brewer Science in 1981. Traditionally, these BARCs have been polyamide platform where the solubility of the BARC in aqueous developer is controlled by the BARC bake process. A representation of the immidization process is shown in Figure 6.

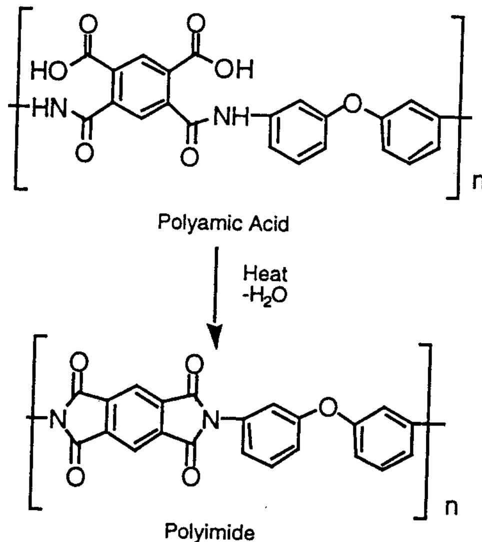

Fig. 6. Schematic diagram representing the immidization Of a polyamic acid into developer insoluble polyimide

For this type of BARC a number of factors contribute to the dissolution of the material in developer. These include: transport of the developer to the surface; adsorbtion of the developer to the surface; the develop reaction; desorbtion of the reacted product from the surface and finally transport of the product away from the surface [9]. Historically, these products were limited to the resolution of the illumination wavelength and above. However, in a move to accommodate for higher functionality and advanced implant process applications, high resolution wet patterning BARC begin to emerge [10]. In addition, traditional polyimide chemistry have limited Bake Window defined in figure 7.

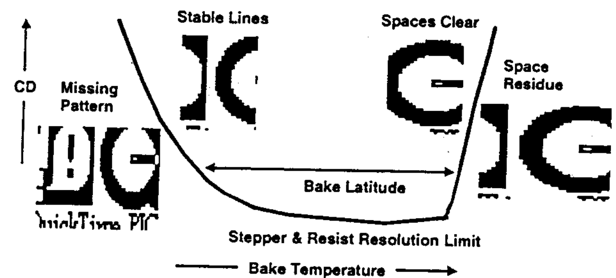

Fig. 7: Definition of bake window, where at too low a temperature lines, lift, and at too high a temperature, scumming occurs in open spaces

But, advanced BARC platforms now provide wide bake windows and are also spin bowl compatible with photoresist solvents. An advanced BARC showing a 30°C bake window is shown in figure 8.

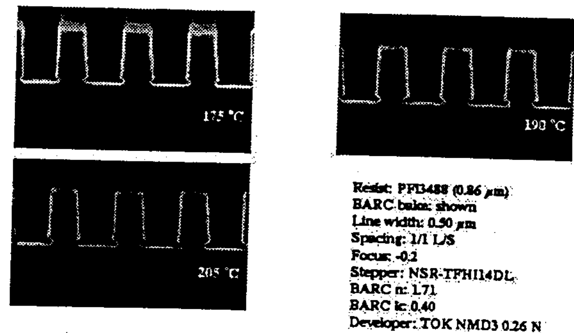

Fig. 8: Bake window of printable BARCs showing 0.5μm Lines with 30°C bake latitude

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For traditional etch applications undercut or vertical BARC profiles are desirable to avoid any contribution to etch bias [11]. Conversely, for implant applications, a vertical profile is desirable [avoiding any unnecessary shadow masking]. To achieve the characteristics of wet patterning BARC, many rigorous criteria must be observed. These include (1) soluble in organic solvent (2) insoluble in resist solvent; (3) soluble in alkaline solution (during the development process), and (4) soluble in the spin bowl. Further to the patterning process, mechanical attributes of BARC design play a key role and shall be described in a later paper.

6. Conclusions

The intention of this article has been to move the organic BARC users forward in their experience of using BARC. From the traditional CD control applications for conventional lithography, to realize the modifications made to the optical parameters, the polymer type and chromophore to facilitate advanced lithography below the wavelength of light. Furthermore, with the advent of advanced implant applications, the introduction of wet patterning BARC for layers other than polysilicon. Firstly the optical parameter optimization was discussed. This can be achieved by utilizing a polymer system which is intrinsically light absorbing as in our first generation BARC, or moving to advanced systems where "light absorbing" groups are attached to the supporting polymer system. Then the inclusion of specific polymers which have fast plasma etch or slow plasma etch behavior. These have particular relevance to sub wavelength lithography and integration as volatile memory require high topography coverage and therefore fast etch BARCs to minimize overetch and resulting CD dispersion. Or, the integration of etch-block BARCs into the Via-first Dual Damascene scheme.

7. Acknowledgments

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