PMMA Characterization and Optimization for Nano Structure Formation

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***Abstract*-The limitations imposed on optical lithography by the wavelength of light have been overcome using electron lithography. Electron lithography offers high resolution because of the small wavelength of the 10-50 keV electrons and not sensitive in near UV. The resolution of electron lithography systems is limited by electron scattering in the resist not by the diffraction. One of the limitations of the resolution is resist thickness besides of beam energy and substrate compositions. Resist thickness is controlled by many factors such as velocity of the spinner, solid content and the viscosity of the resist. The resist commonly used on electron lithography is PMMA or Polymethyl-Methacrylate. In this paper, the effect of three parameters (as concerned above) on resist thickness is focused.**

Keywords: Electron beam lithography, resolution, resists thickness, PMMA.

I. INTRODUCTION

Polymethyl-Methacrylate (PMMA) is probably the highest resolution positive organic resist suitable used for the electron beam lithography (EBL) as well as deep UV, X-ray and focused ion beam microlithography processes [1]. PMMA is a versatile polymeric material that has been exploited for a variety of imaging and non-imaging microelectronic applications, including use as a radiation-sensitive patterning layer [2], as a protective or structural layer [2], as a protective coating for wafer thinning [3], as a bonding adhesive [3] and as a sacrificial layer [3].

The thickness of the resist is important parameter to get the best resolution in lithography. Since the thicker resist causes resolution problems due to scattering of beam energy [1], the thinner layer is preferable. Thin resist layers alleviate some high-energy imaging problems and produce better electron beam resolution [4]. Resist thickness is influenced by many factors, such as solid content and viscosity of the resist, but the primary determination of the thickness is the spinner rotational [4].

Spin resist on wafer surface is one of the lithography processes. The goal of spin coating is to produce a thin, uniform, defect free layer of desired thickness over the wafer surface [5]. The resist solution is dispensed onto the wafer and spreads over the whole wafer as the spinner spun rapidly based on spin speed determined. The higher spin speed, the thinner resist layer will form [6].

During spinning process, the solvent in the resist evaporate rapidly. The evaporate solvent may cause the weight percent of solids content increase [5]. Since viscosity is closely related to solids content, the increasing percentage of solids content may increase the viscosity too [5]. Therefore, decreasing the solid content will decrease the viscosity and subsequently the thinner resist layer will obtained and it is shown graphically in references [3], [5], [6] and [7].

In this paper, we are discussing the effect of spin speed, solids content and viscosity for PMMA 495K A2, 495K A4, 950K A2 and 950K A4.

II. RESEARCH METHODOLOGY

In this experiment, we used six P-type silicon wafer of <100> orientation with thickness of 475-575 μm and resistivity of 1- 20 μΩ. These wafers are cut into 4 pieces $\left(\frac{1}{4}\times 4''\right)$. All of the wafers are coded for identification purpose and indicate as A(1-6), B (1-6), C (1-6) and D (1-6). PMMA resists used in this experiment

PMMA is a positive resist which based on polymeric material; Polymethyl Methacrylate. It has different molecular weight that ranging from 50,000 to 2.2 million [6]. The high MW resist commonly used is 950K and the lower MW used is 495K. 495K and 950K represent molecular weight resins [6] and A2 and A4 is a solid content in solvent Anisole [8, 9]. In addition, the viscosities of solution are 5.28 cst for PMMA 495K A2, 14.2 cst for PMMA 495K A4, 10.8 cst for PMMA 950K A2 and 41.50 cst for PMMA 950K A4 [8, 9]. All have been summarized in table below.

TABLE 1: PMMA SPECIFICATIONS

No	Resist / PMMA	Molecular Weight	Solids Content, %	Viscosity , cst
1.	495 K A2	495 000	2	5.28
2.	495 K A4		4	14.20
3.	950 K A2	950 000	2	10.80
4.	950 K A4		4	41.50

There are three major steps in wafer coating, which are, wafer cleaning, resist coating and thickness measurement.

All wafers are cleaned using SC1 (standard clean). The wafers are dipped in the solution at 75°C for 10 minutes and rinse with DI Water. Without any delay, the wafers then were dipped in BOE for 10-15 seconds and rinse again with DI Water. Then the last step in cleaning, the wafers are dipped in RCA2 for about 10-15 minutes at 80°C. After rinse with DI Water, the wafers are then spin dry using spinner at 3000 rpm for 20 seconds.

After cleaning, the wafers are baked in convention oven for 5 minutes at 100°C to remove residual water during cleaning process. Then the wafers are leave to cool down in ambience about 2-3 hours. After that, coating process is started. For wafers indicated as A (1-6), 495K A2 resist is used while B (1-6) used 495K A4 resist, C (1-6) used 950K A2 and D (1-6) used 950K A4. (1-6) represent the spin speed used during coating process, for instance, 1 represent 1000 rpm.

As the objective of this experiment is to find correlation between spin speeds and resist thickness, the spin time is set to fix while spin speeds are varied. Therefore after ramp-up, with 500 rpm for 10 seconds, the wafers are spanned for 45 seconds for each spin speeds; 1000, 2000, 3000, 4000, 5000 and 6000 rpm on different wafers. Then the last step is ramping down for 5 seconds with 0 rpm. After coating, wafers are baked on hot plate at 180°C for 60-90 seconds. It is recommended to leave the coated wafer overnight before any characterization is being done.

The last step is thickness measurement. The coated wafers are measured using spectrophotometer. Five points are measured on the wafer and the average of the thickness is considered as resist thickness.

I. Results And Discussions

The data gained from experiment conducted are tabulated in Table 2, 3 and 4. It shows correlation between spin speed (rpm) and resist thickness (nm) and graphically shown in Graph 1, 2 and 3 below.

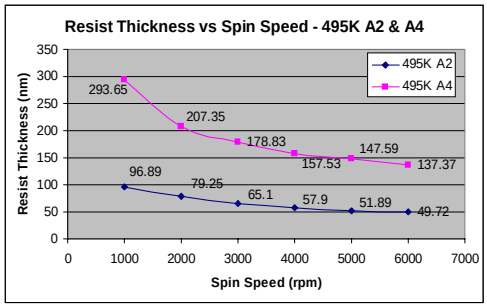
Graph 1 represent the result of using PMMA 495K A2 and A4 while Graph 2 represent result using PMMA 950K A2 and A4. As shown in graphs below, as spin speed increase the resist thickness obtained is decreased.

For PMMA 495K, the thinnest resist layer formed is 49.72 nm with 2% solids content in Anisole. While for PMMA 950K, the resist thickness obtained is 62.33 nm with 2% solids content in Anisole. This thinnest layer achieved at 6000 rpm of spin speed.

Both resist gained the thinner layer have lowest composition of solids content. As explained before, solids content contribute to resist layer formation and closely related with viscosity. As PMMA 495K A2 and PMMA 950K A2 having lower solids contain and viscosity, the thinner resist layers are successfully form compared to PMMA 495K A4 and PMMA 950K A4.

TABLE 2
RESIST THICKNESS VERSUS SPIN SPEED - 495K A2& A4

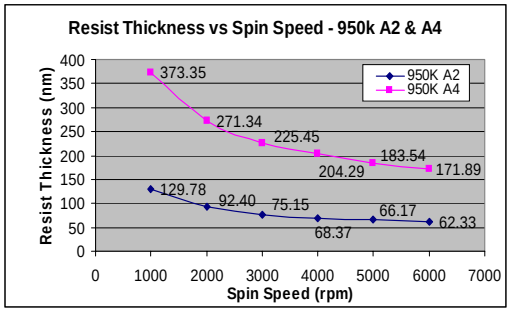
No.	Spin Speed (rpm)	Resist Thickness (nm) - 495K A2	Resist Thickness (nm) - 495K A4
1	1000	96.89	293.65
2	2000	79.25	207.35
3	3000	65.10	178.83
4	4000	57.90	157.53
5	5000	51.89	147.59
6	6000	49.72	137.37



Graph 1. Graph Resist Thickness vs. Spin Speed for PMMA 495K A2 & A4.

TABLE 3
RESIST THICKNESS VERSUS SPIN SPEED - 950K A2& A4

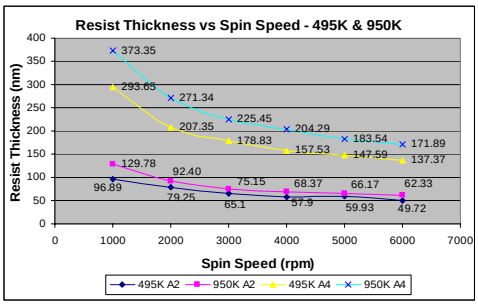
No	Spin Speed (rpm)	Resist Thickness (nm) - 495K A2	Resist Thickness (nm) - 495K A4
1	1000	129.78	373.35
2	2000	92.40	271.34
3	3000	75.15	225.45
4	4000	68.37	204.29
5	5000	66.17	183.54
6	6000	62.33	171.89



Graph 2. Graph Resist Thickness vs. Spin Speed for PMMA 950K A2 & A4.

TABLE 4
RESIST THICKNESS VERSUS SPIN SPEED – 495K & 950K

No	Spin Speed (rpm)	Resist Thickness (nm) - 495K A2	Resist Thickness (nm) - 950K A2	Resist Thickness (nm) - 495K A4	Resist Thickness (nm) - 950K A4
1	1000	96.89	129.78	293.65	373.35
2	2000	79.25	92.40	207.35	271.34
3	3000	65.10	75.15	178.83	225.45
4	4000	57.90	68.37	157.53	204.29
5	5000	51.89	66.17	147.59	183.54
6	6000	49.72	62.33	137.37	171.89



Graph 3. Graph Resist Thickness vs. Spin Speed for PMMA 495K & 950K - A2 & A4.

All the data have been tabulated and shown in Table 4 and Graph 3. PMMA 495K A2 produce thinnest layer compared to others. PMMA 495K A2 has a smallest number of solid content and viscosity.

In addition, the choice of PMMA molecular weight is of concerned too especially in multilayer processes. As a resolution positive tone resist, the scission of molecular chains by the incident of electrons is predominant. The exposed region leading to lower molecular weight makes the polymer easily soluble in a suitable developer. Generally, dissolution rate increases as molecular weight decreases [6]. It contributes to better resist profile with sharp edges and step sidewalls [4]. The molecular weight commonly concerned in T-gate and metal lift-off applications [5].

I. CONCLUSION

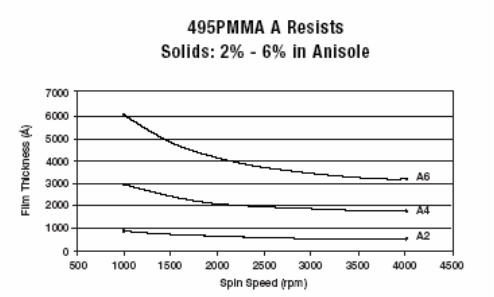


Figure 5. Spin Speed Versus Film Thickness Curves.

Refer to the results obtained, the fastest spin speed, 6000 rpm with 45 seconds fix spin time, the thinnest resist layer can be obtained and it is merely to the reference of spin speed versus film thickness curves provided by MicroChem Corporation (Figure 5)

As a conclusion, these three parameters; spin speed, solids content and viscosity; have contribution in forming thin resist layer on the wafer. The higher spin speed will spread the resist evenly on the wafer and produced thin layer of resist and it is induced by lower solids content and viscosity of the resist. Molecular weight is not really affected in resist thickness formation. According to Graph 3 above, even PMMA 950K A2 has higher molecular weight than PMMA 495K A4, but the solids content and viscosity of the resist is lower than PMMA 495k A4, and as a result it produce thinner resist layer.

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