FABRICATION OF T-GATE STRUCTURES USING DOUBLE LAYER E-BEAM LITHOGRAPHY

Eric A. Lehner
Senior Microelectronic Engineering Student
Rochester Institute of Technology

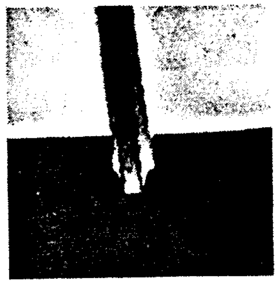
ABSTRACT

The fabrication of T-gate structures using a bilayer resist scheme of PMMA 495K molecular weight (4% solids) and PMMA 950K molecular weight (3% solids) for use with electron beam exposure was investigated. The 1.18 sensitivity ratio between these resists was found to be insufficient to adequately provide the resist cavity necessary for fabrication of T-gate aluminum structures.

INTRODUCTION

With the ever decreasing device dimensions in silicon and GaAs technology, the demand for field effect transistors (FETs) possessing high performance, especially high electron mobility transistors (HEMTs) continues to increase. It is well known that short gate length and low gate resistance are essential for the high performance of these FETs [1,2,3]. Gate lengths of 50-100nm have been fabricated [4] in order to minimize the transit time of electrons through the gate region. However, as the cross-sectional area of the gate is reduced, the resistance of the gate increases proportionately, resulting in degraded device performance. One solution to this problem is a T-gate structure in which the base of the gate is kept small while the top of the gate is made wider to increase its cross-sectional area and hence its electrical conductivity. For example, Atwood [5] compared conventional 0.25um rectangular gates with T-gates of the same base dimension, and found that the T-gates had median resistances about 2.5 times smaller than that of the conventional gates, while greatly improving the maximum attainable gain at frequencies greater than 10 GHz.

Numerous lithographic techniques have been developed to fabricate T-gates. Todokoro reported the use of PMMA and a proprietary resist (MPR) in a bilayer HI/LO sensitivity scheme for fabrication of mushroom-type gates [6]. Figure 1(a) shows a SEM profile of a 0.5um-MPR/0.5um-PMMA resist film exposed at 220uC/cm2 and developed with 1:3 MIBK:IPA developer for 90 seconds. Figure 1(b) shows the mushroom type metal gate, having a 0.4um wide base and a 0.7um wide crown, formed after liftoff. Tiberio reported a trilayer resist scheme using PMMA and its methacrylate acid copolymer (PMMA/MAA) together with a three step selective developer process [4] in order to form T-gate structures as shown in Figure 2.

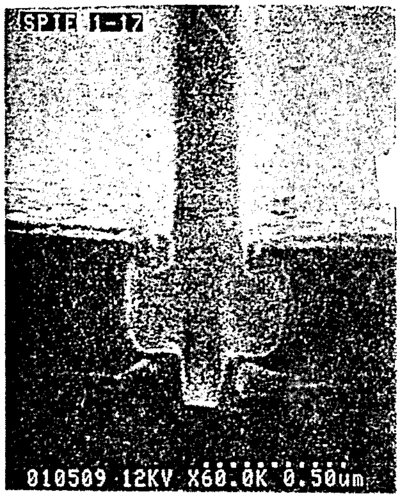


(a)

(b)

Figure 1: (a) Todokoro MPR/PMMA resist profile.
(b) Mushroom gate with 0.4um base [6].

(a)



(b)

Figure 2: a) Multilevel PMMA resist cross-section.
b) 100nm T-gate after liftoff [4].

Another scheme, investigated by Kato [7], utilized a high sensitivity EBR-9 resist and a lower sensitivity PMMA resist. The key to this double-layer resist technique was to exploit the sensitivity difference of the two resists, in order to obtain an undercut top resist profile and an overcut bottom resist profile. In the simulations conducted by Kato, a resist sensitivity ratio of 3.3 was found to yield desired profiles, as shown in Figure 3. These profiles clearly show the undercut profile resulting from the tear-drop shaped exposure, predicted by Monte-Carlo simulation. Kato reported, however, that it is difficult to produce T-shaped resist cavities when the top resist has less than 1.4 times higher sensitivity than the bottom resist.

This project utilized PMMA, with a molecular weight of 950K, as the high sensitivity top resist, and PMMA, with a molecular weight of 495K, as the lower sensitivity bottom resist. By examining the dissolution characteristics of these resists resulting from various exposure doses and various concentrations of methyl isobutyl ketone (MIBK):isopropyl alcohol (IPA) devoloper, a sufficiently high sensitivity ratio should be found which allows for a well-defined undercut / overcut resist profile to be formed. This resist profile should allow for the fabrication of T-gate structures by aluminum evaporation and acetone liftoff.

resist was baked at 180C for 30 minutes, followed by two ~0.27um coats and bakes of PMMA (950K, 3% solids). Resist thickness was measured with the Nanospec after each bake to confirm the absence of interfacial mixing.

Using the optimized exposure dose range, developer concentration, and development time determined from the sensitivity curves, 3 wafers were exposed at doses of 50, 55, and 60uC/cm2 with a 10KeV electron beam and developed. The resist profiles were examined with a SEM to determine the presence of an undercut profile in the top resist layer and an extension of the bottom resist layer. The process wafers which exibited a potential T-gate resist structure were evaporated with approximately 0.4um of aluminum, acetone soaked for liftoff, and returned to the SEM to examine the final gate structure.

RESULTS/DISCUSSION

Table 1 summarizes the sensitivities which were found when ~5600A PMMA 495K, and PMMA 950K resist samples were exposed and developed in 7:3, 4:1, and 5:1 MIBK:IPA developers at 30 second intervals.

Table 1: PMMA 495K, PMMA 950K Sensitivities (uC/cm2)

DEVELOPMENT TIME (sec.)	7:3 MIBK:IPA		4:1 MIBK:IPA		5:1 MIBK:IPA	
	495K	950K	495K	950K	495K	950K
30	84	80	80	80	80	80
60	70	60	60	60	60	60
90	**60**	**51**	51	48	52	52
120	54	47	46	42	46	45
150	42	41	40	38	40	40
180	38	37	37	-	36	36
210	35	-	34	-	-	-
240	-	-	-	-	-	-

The sensitivity differences between the two resists were found to be the most pronounced when 7:3 MIBK:IPA developer was used and tended to decrease as the concentration of MIBK in the developer increased. The largest sensitivity ratio of 1.18 between the resists occurred using a 90 second development with PMMA 950K having a sensitivity of 51 uC/cm2 and PMMA 495K having a sensitivity of 60 uC/cm2. The optimum exposure dose required to obtain the desired undercut/overcut profile using these developing conditions was therefore determined to be approximately 55 uC/cm2. It must be noted however, that this sensitivity difference is less than the 1.4 sensitivity ratio required to produce T-shaped resist cavities, as reported by Kato.

Coating of the bilayer resist scheme, resulted in no gross interfacial mixing between the resist layers as varified by Nanospec measurements, as shown in Table 2.

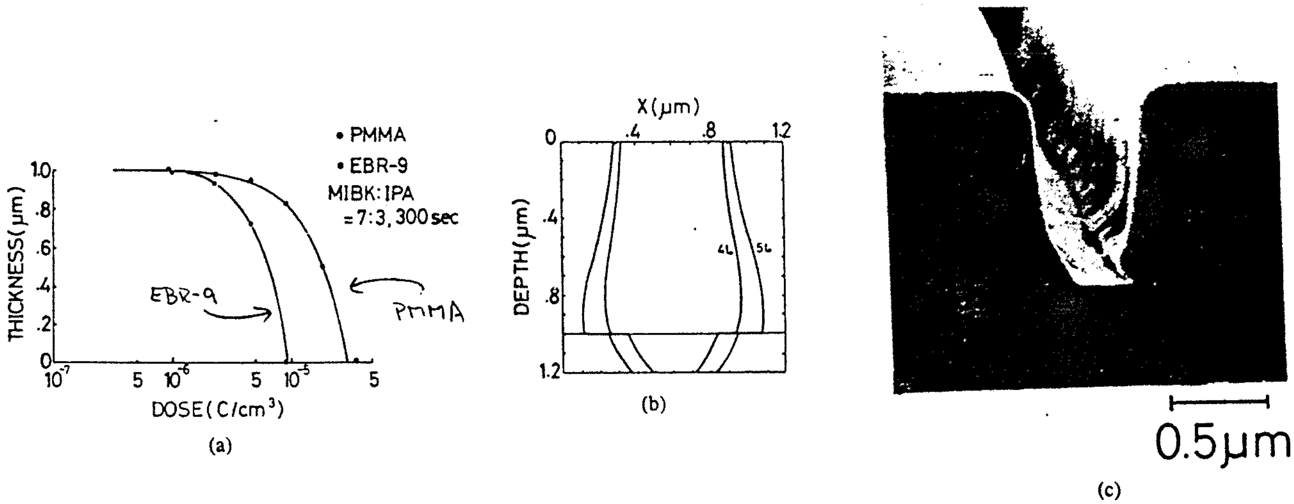


Figure 3: (a) Dissolution characteristics of EBR-9 and PMMA exposed with a 20-KeV electron beam (b) Corresponding simulated developed profile of 0.1um isolated line written with a 2.0e-5 C/cm2 dose (c) Resulting SEM cross-sectional profile with 0.2um base opening [7].

EXPERIMENT

Verification of the manufacturer's spin speed curves was done by manually coating MEAD Technologies PMMA, 495K molecular weight (6% solids) and MEAD Technologies PMMA, 950K molecular weight (3% solids) resists at 1000, 2000, 3000, and 4000 rpm, onto eight 4-inch, silicon wafers. Following a 30 minute convection oven bake at 180C, resist thicknesses were measured on a Nanometrics Nanospec.

Three 4-inch, silicon wafers were then coated with approximately 5600A of each resist. The 950K PMMA required a double coat/bake to achieve this thickness, since a single coat at 2000rpm results in an approximate thickness of 2700A, and the use of a 10-KeV electron beam requires a total resist thickness of approximately 0.5um-0.7um. A MEBES I e-beam tool was used to expose the wafers with 1,2,4,6,10,20,40,60,80,100uC/cm2 doses. A 0.5um spot size and a beam current of 40nA were also used to expose a line-space test pattern with a minimum dimension of 1 micron. The wafers were then developed at 30 second increments in 7:3, 4:1, and 5:1 concentrations of MIBK:IPA developer.

Sensitivity curves for each resist under each developing condition were found, as well as the time necessary to fully develop each sample, by determining the index of refraction and resist thickness remaining after each development using an ellipsometer and Nanometrics Nanospec. By comparing these sensitivity curves, the optimum exposure dose range, developer concentration, and development time required to obtain an undercut/overcut profile in a double layer PMMA(950K)/PMMA(495K) resist scheme were found.

Using the Thomas "Cross Relationship" PMMA (495K, 6% solids) was diluted to a 4% solids formulation by adding chlorobenzene, in order to be able to coat a 0.2um bottom resist layer. This

Table 2: Thickness Measurements During Bilayer Resist Coating

Coating Condition	Spin Speed	Expected Thickness	Measured Thickness after 30 min. 180C bake
PMMA 495K, 4% solids	4000rpm	2000A	1948.6A
PMMA 950K, 3% solids	2000rpm	4700A	4573.8A
PMMA 950K, 3% solids	2000rpm	7400A	7346.5A

Exposure of the bilayer-resist coated wafers to a dose of 55 uC/cm2, followed by a 90 second development in 7:3 MIBK:IPA developer, resulted in the resist profile of Figure 4. A 0.2um extention of the bottom PMMA 495K resist layer was clearly evident while the top PMMA 950K resist layer appeared to possess a slightly downward curving profile instead of an undercut profile.

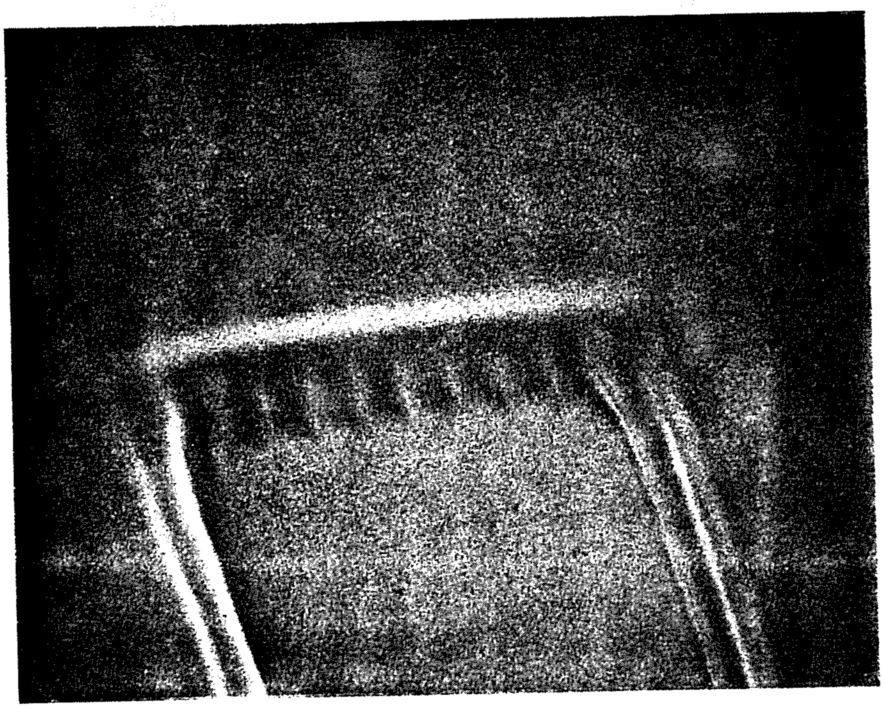


Figure 4: 6um space with ~0.2um bottom resist extension.

Upon aluminum deposition and acetone liftoff of a similarly exposed and developed bilayer resist wafer, an exposure dose of 55 uC/cm2 was insufficient for liftoff. Use of a 60 uC/cm2 dose, however, allowed liftoff to occur, as shown in Figure 5. It is suspected that this exposure dose was sufficient for liftoff, since this dose would result in more vertical sidewalls compared with using a 55 uC/cm2 exposure dose. Since the bilayer resist scheme was approximately 0.7um thick, while only 0.4um of aluminum were deposited, 0.3um of aluminum-free resist would be available for liftoff.

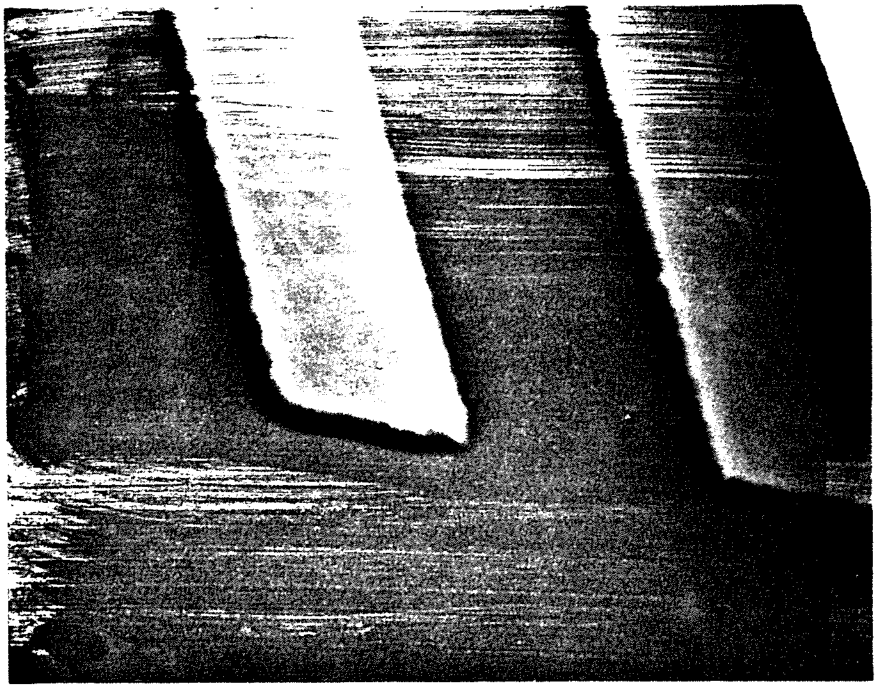


Figure 5: 6um aluminum lines formed from resist profile exposed at 60uC/cm2.

CONCLUSIONS

Use of a bi-layer PMMA 495K / PMMA 950K resist scheme to fabricate T-gate structures was found to be inadequate due to an insufficiently low sensitivity ratio of only 1.18 between the resists. By optimizing exposure dose and development conditions, a 0.2um extension of the bottom resist layer was obtained. However, no undercut profile of the top resist layer was obtained, thus preventing liftoff and T-gate structure formation.

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