Direct comparison of the performance of commonly used e-beam resists during nano-scale plasma etching of Si, SiO_2 and Cr

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Introduction

We report a systematic study of the plasma etch resistance of several e-beam resists, both negative and positive as well as classical and Chemically Amplified Resists: HSQ (Dow Corning), PMMA (Allresist GmbH), AR-P6200 (Allresist GmbH), ZEP520 (Zeon Corporation), CAN028 (TOK), CAP164 (TOK), and an additional pCAR (non-disclosed provider). Their behaviour under plasma exposure to various nano-scale plasma etch chemistries was examined (using SF_6/C_4F_8 ICP silicon etch, CHF_3/Ar RIE SiO_2 etch, Cl_2/O_2 RIE and ICP chrome etch, and HBr ICP silicon etch). Samples of each resist type were etched simultaneously to provide a direct comparison of their etch resistance.

The e-beam exposure was carried out on a Vistec SB254 (Vistec Electron Beam GmbH). This is a Variable Shaped Beam system operating at 50 kV which is applied for patterning resist masks for Electron Beam Direct Write (EBDW) on Silicon and III-V semiconductor materials, for Mask Writing on Quartz substrates as well as for optical and emerging applications. Etching was carried out in a PlasmaPro100 Cobra etch tool from Oxford Instruments Plasma Technology.

Feature widths down to 30nm were e-beam written. Trench widths down to 30nm were produced for most of the resist types, however it was decided to compare Silicon etch profiles using 50nm wide features in order to provide a full set of SEM data. The etch processes were not specifically optimised for selectivity, so should be representative of typical results.

Results

Resist	Type	Softbake	Base dose in µC/cm²	PEB	Development	Thickness after development
HSQ (XR-1541)	Negative nonCAR	150ºC, 120”	2700	no	4 min in 4% NaCl + 1% NAOH	90nm
PMMA 600k (AR-P 661)	Positive nonCAR	180ºC, 60”	250 (slightly overexposed)	no	30” in MIBK:IPA=1:1	105nm
AR-P 6200	Positive nonCAR	150ºC, 60”	90	no	60” in AR 600-546 (Amylacetate)	115nm
ZEP 520	Positive nonCAR	180ºC, 60”	75	no	60” in ZED-N50 (Amylacetate)	100nm
CAN028	Negative CAR	110ºC, 90”	12 (overexposed by approx. 20%)	110ºC, 60”	30” in NMD-W (2.38% TMAH)	110nm
CAP164	Positive CAR	100ºC, 90”	75	100ºC, 90”	60” in NMD-W (2.38% TMAH)	100nm
pCAR	Positive CAR	130ºC, 60”	160	110ºC, 90”	30” in NMD-W (2.38% TMAH)	55nm

Fig. 1. Main exposure and processing conditions, based on the suppliers recommendations.

Pre-etch resist profiles - 50nm features

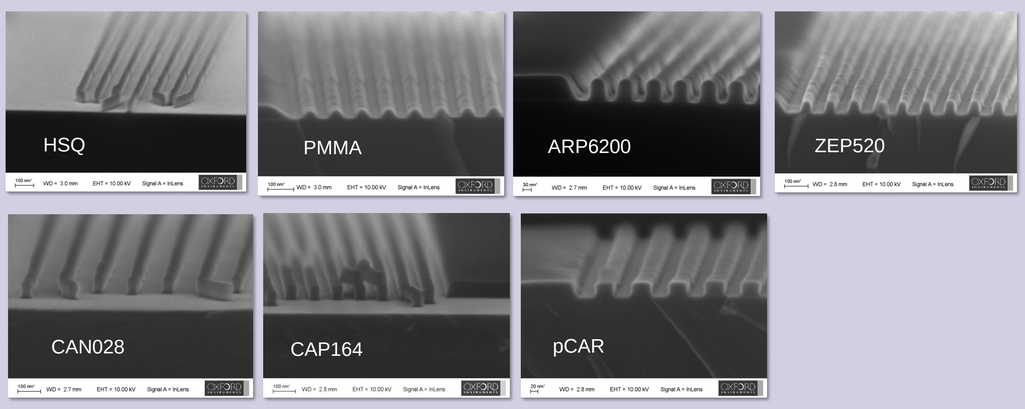

Fig. 2. Pre-etch profiles of 50nm wide lines on Silicon substrate – to be used for subsequent HBr and SF_6/C_4F_8 etch trials.

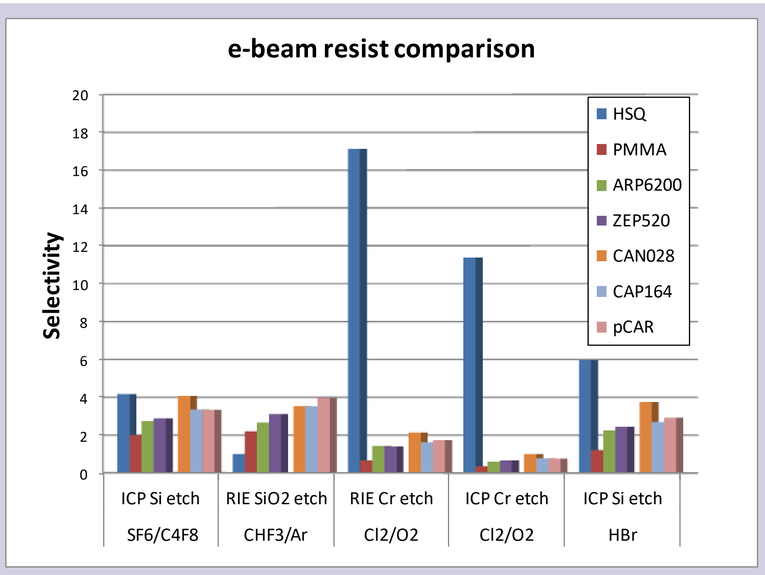

Fig. 3. Selectivity comparison for various process types.

Resist	SF_6/C_4F_8 ICP Si etch	CHF_3/Ar RIE SiO_2 etch	Cl_2/O_2 RIE Cr etch	Cl_2/O_2 ICP Cr etch	HBr ICP Si etch
HSQ	4.16	0.99	17.11	11.38	5.96
PMMA	2.00	2.19	0.67	0.38	1.20
ARP6200	2.74	2.67	1.44	0.61	2.25
ZEP520	2.89	3.12	1.41	0.67	2.43
CAN028	4.07	3.53	2.13	1.01	3.76
CAP164	3.35	3.52	1.63	0.78	2.71
pCAR	3.33	3.96	1.74	0.77	2.93

Fig. 4. Selectivity comparison for various process types.

HBr ICP etching resulted in anisotropic Si profiles with minimal lateral erosion of resist

Chemically amplified resists and HSQ produced the best etch profiles

SF_6/C_4F_8 ICP etching resulted in anisotropic Si profiles with some lateral erosion of resist, dependent on resist type and starting profile

50nm features HBr Si Etch

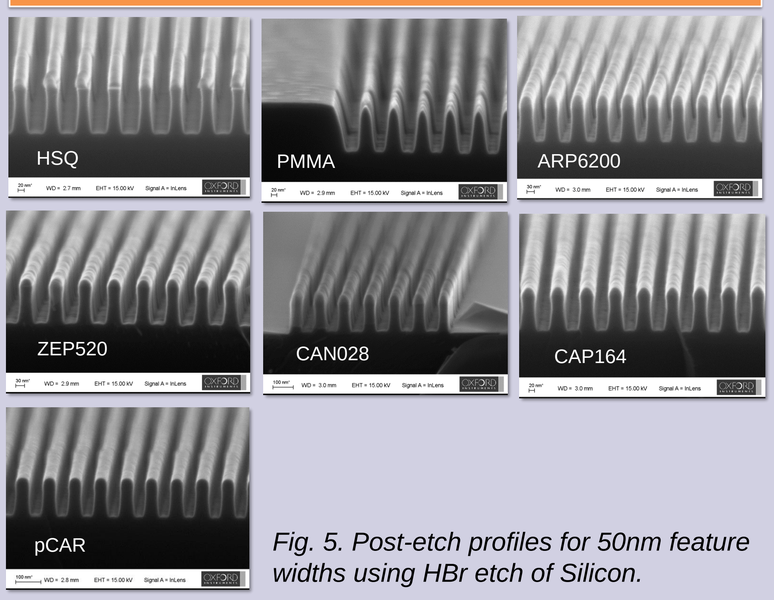

Fig. 5. Post-etch profiles for 50nm feature widths using HBr etch of Silicon.

50nm features SF_6/C_4F_8 Si Etch

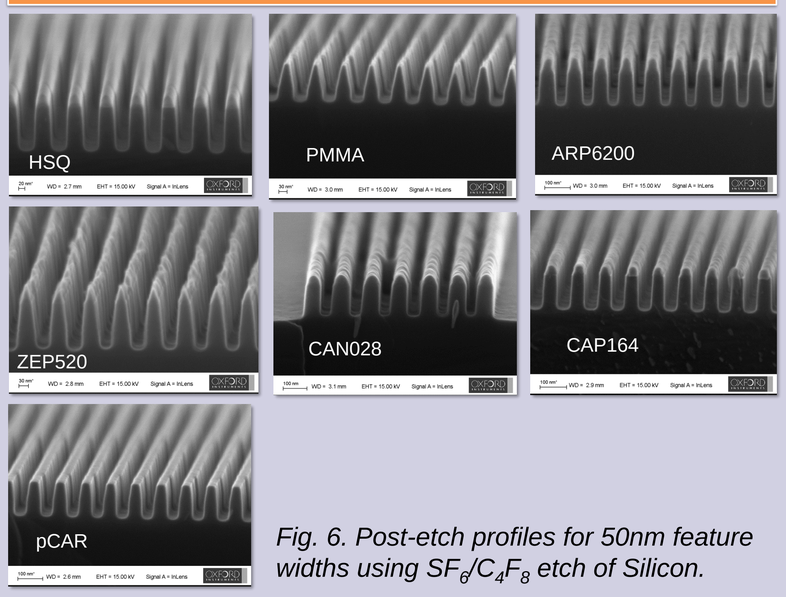

Fig. 6. Post-etch profiles for 50nm feature widths using SF_6/C_4F_8 etch of Silicon.

Conclusions

In this study seven electron-beam resists were evaluated concerning their behaviour under plasma exposure to various nano-scale plasma etch chemistries.

HSQ performed well in all processes except for SiO_2 etching, and produced high resolution patterns, so would be the recommended resist if its increased processing requirements and very high dose can be tolerated. The three chemically amplified resists (CAP164, CAN028, pCAR) also showed good selectivity performance and good etch profiles, with CAN028 giving the higher selectivity for most processes. Of the other resists (AR-P6200, ZEP520, PMMA), AR-P6200 produced the best etch profiles, although this may be because it was a slightly thicker layer. The etch selectivity and etch profiles of all tested resists were significantly better than PMMA, and (apart from HSQ) required a lower exposure dose.

To summarize, the results give an indication of the etch selectivity and profile that can be achieved with various e-beam resists and etch chemistries. Depending on the application and the resist type, the resist process and etch chemistry should be carefully selected to produce the optimum result.

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