Positive PMMA E-Beam Resists AR-P 630 – 670 series

AR-P 631-679 e-beam resists for nanometer lithography

PMMA resist series 50K – 950K for the production of integrated circuits and masks

Characterisation

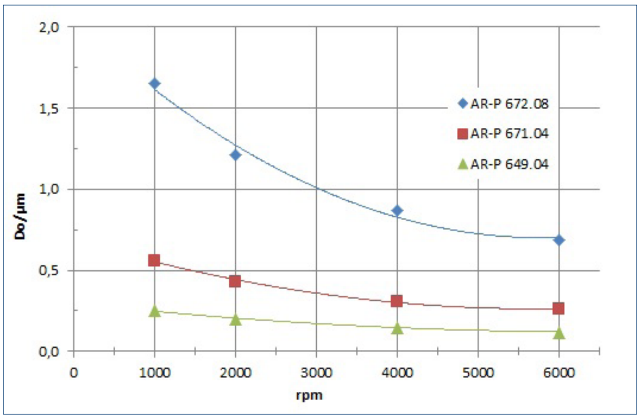
- e-beam, deep UV (248 nm)
- very good adhesion to glass, silicon and metals
- 50K 20 % more sensitive than 950K
- for planarization and multi-layer processes
- highest resolution, high contrast
- poly(methyl methacrylate) with diff. molecular weights
- AR-P 641-671 solvent chlorobenzene, flash p. 28 °C
- AR-P 632-672 safer solvent anisole, flash p. 44 °C
- AR-P 639-679 safer solvent ethyl lactate, flash p. 36 °C

Properties I

Parameter / AR-P	632-639	641-649	661-669	671-679
PMMA type	50 K	200 K	600 K	950 K
Film thickness/ 4000 rpm (nm) according to solids content	0.02-0.31	0.02-0.78	0.02-1.04	0.03-1.87
Solids content (%)	1-12	1-12	1-11	1-11
Resolution best value (nm)	6			
Contrast	7			
Storage temperature (°C) *	10 - 22			

* Products have a guaranteed shelf life of 6 months from the date of sale if stored correctly and can also be used without guarantee until the date indicated on the label.

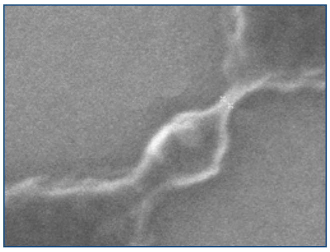
Spin curve



Properties II

Glass trans. temperature (°C)	105	
Dielectric constant	2.6	
Cauchy coefficients	N_0	1.478
	N_1	47.3
	N_2	0
Plasma etching rates (nm/min) (5 Pa, 240-250 V Bias)	Ar-sputtering:	21
	O_2	344
	CF_4	59
	80 CF_4 + 16 O_2	164

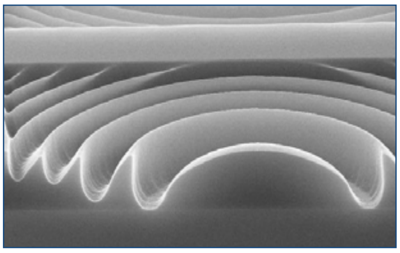
Structure resolution



AR-P 679.02

Structural resolution: 6.2 nm gap, 65 nm high

Resist structures



AR-P 671.09 diffractive optics, thickness of 4.4 µm

Process parameters

Substrate	Si 4“ waver
Soft bake	150 °C, 3 min. hot plate
Exposure	Raith Pioneer, 30 kV
Development	AR 600-56, 60 s, 21 °C
Stopper	AR 600-60, 30 s, 21 °C

Process chemicals

Adhesion promoter	AR 300-80 new
Developer	AR 600-55, AR 600-56
Thinner	Chlorobenzene or AR 600-02, 600-09
Stopper	AR 600-60
Remover	AR 600-71, AR 300-76

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Process conditions

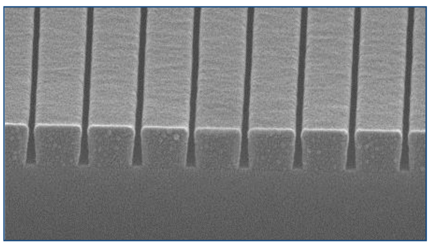
This diagram shows exemplary process steps for resists of the series AR-P 630 - 670. All specifications are guideline values which have to be adapted to own specific conditions. For further information on processing, ☞ "Detailed instructions for optimum processing of e-beam resists". For recommendations on waste water treatment and general safety instructions, ☞ "General product information on Allresist e-beam resists".

Coating	AR-P 632.06	AR-P 671.05
	4000 rpm, 60 s, 110 nm	2000 rpm, 60 s, 690 nm
Soft bake (± 1 °C)	150 °C, 3 min hot plate or	
	150 °C, 60 min convection oven	
E-beam exposure	ZBA 21, 20 kV	Raith Pioneer, 30 kV
	Exposure dose (E_0):	
	95 $\mu C/cm^2$	770 $\mu C/cm^2$
Development (21-23 °C ± 1 °C) puddle	AR 600-55 1 min	AR 600-56 3 min
Stopping	AR 600-60, 30 s	
Post-bake (optional)	130 °C, 1 min hot plate or 130 °C, 25 min convection oven for slightly enhanced plasma etching resistance	
Customer-specific technologies	Generation of semiconductor properties	
Removal	AR 300-71 or O_2 plasma ashing	

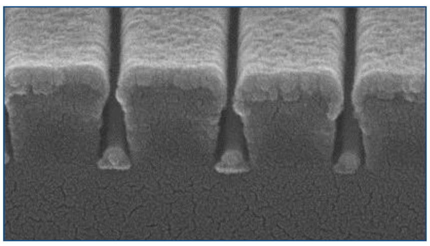
Processing instructions for coating

Large undercut structures (lift-off) are obtained if PMMA resists with different molecular weight are chosen for a two component system. As upper layer, an ethyl lactate PMMA is recommended since ethyl lactate does not, in contrast to other solvents, attack the second layer. For the lower layer, a chlorobenzene, anisole or ethyl lactate PMMA is suitable. Both tempering steps are performed at 150 °C.

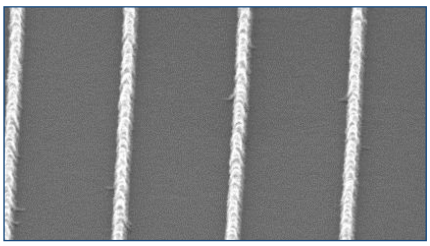
Recommendation: large undercut (low resolution): bottom layer 50K, upper layer 200K, 600K or 950K. High resolution (smaller undercut): bottom layer 600K, upper layer 950K.



After development (AR 600-56)



Structures coated with metal films



Lifted 30 nm metal lines

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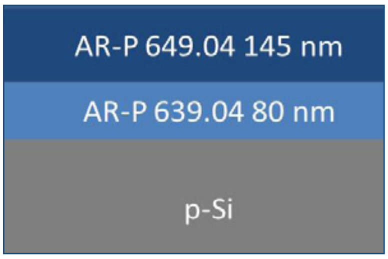
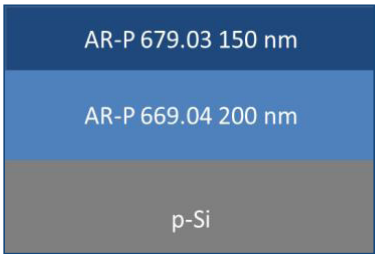
Investigations of 2-layer PMMA lift-off structures



Layer structure of the two-layer system 50K/200K



Layer structure of the two-layer system 600K/950K

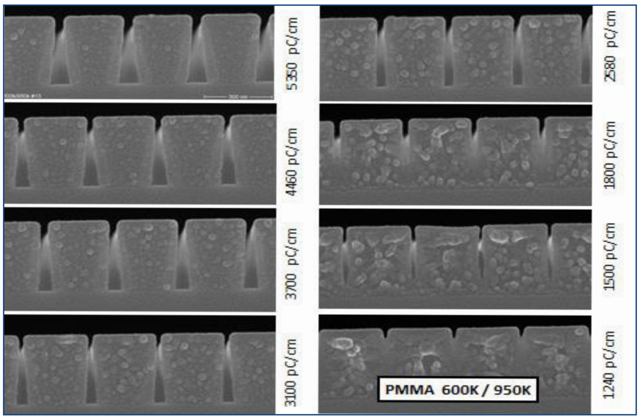
For these tests, the 2-layer systems were coated as shown to the left and tempered at 180 °C, 60 s, followed by irradiation with different doses (30 kV) and development (AR 600-60, IPA).

The system 50K/200K is more sensitive, the double layer is completely developed at 1500 pC/cm². The variant 600K/950K in contrast requires the higher dose of 2200 pC/cm². With increasing dose, also a larger undercut is generated if the 50K/200K system is used, which is thus predestined for complicated lift-off procedures. Variant 600K/950K may be utilised for higher total film thicknesses (> 500 nm) and is a reliable lift-off system for simple applications. For these investigations, always AR 600-60 (IPA) was used as developer which explains both the comparably high doses and the good process stability.

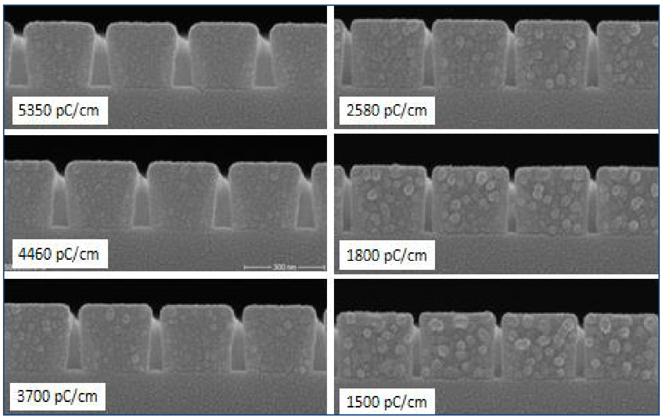
Dose sequence of the 600K/950K system

Dose-scale of 50K/ 200K systems

Definition: The sensitivity is expressed in pC/cm for lines, while the unit for areas is µC/cm².

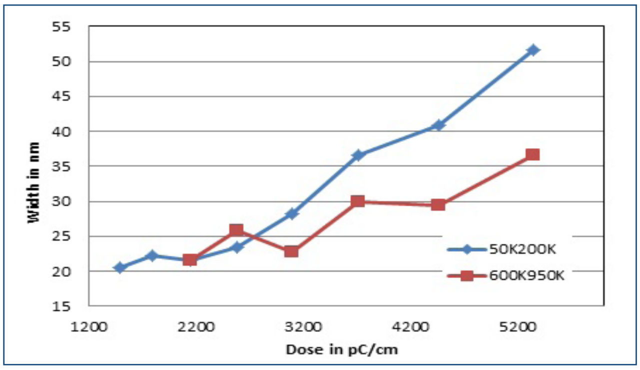


Not yet completely developed at 1800 pC/cm



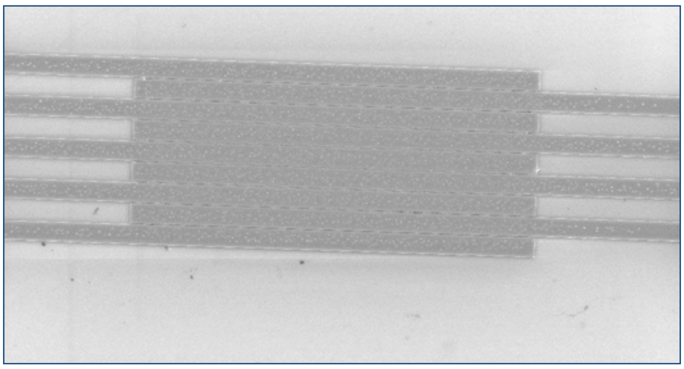
Constantly increasing undercut

Formation of undercut vs. exposure dose



Trench width top: 20 nm, measured values in the diagram: width of trenches at the bottom

Application example



“Finger structures“ produced with the special system PMMA 90k/200K, trench width 30 nm

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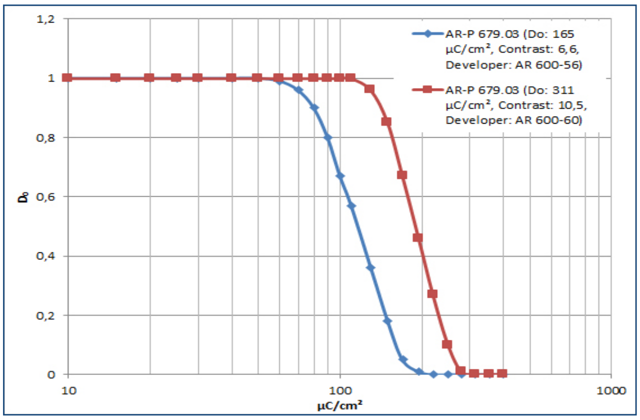
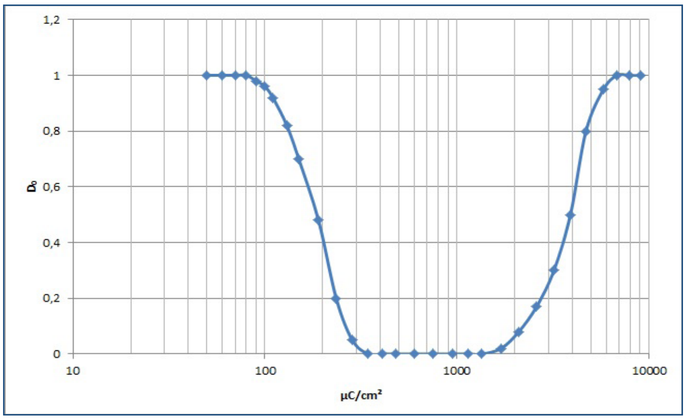
Sensitivity of a PMMA resist



Comparison of developer AR 600-55 and AR 600-56

Gradation curve PMMA



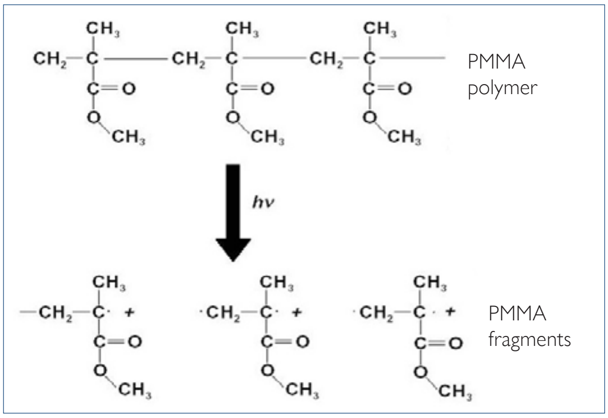
Gradation curve up to maximum dose

The left diagram shows a comparison of the sensitivity of AR-P 679.03 in two different developers. Under otherwise identical conditions (30 kV, 165 nm film thickness), the sensitivity is almost twice as high if the standard developer AR 600-55 is used as compared to AR 600-60 (IPA). A development with IPA however results in a considerably higher contrast (10.5 : 6.6). This developer is thus predestined for higher resolutions. Experience furthermore shows that the process window is significantly larger as compared to faster developers.

Dose deviations of e.g. 10 % are tolerated without any quality loss.

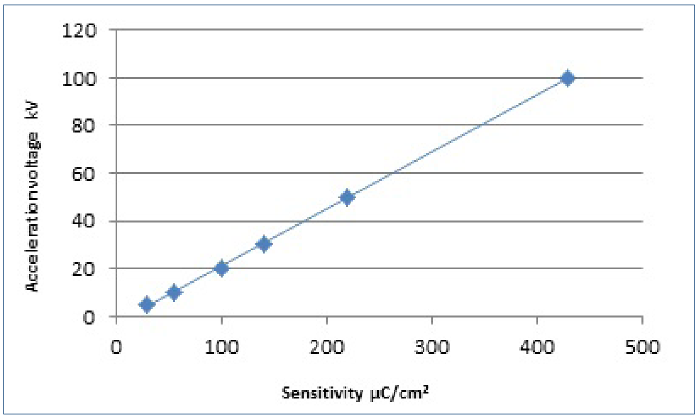
Upon electron irradiation of PMMA resists, the main chain is cleaved and the molecular mass drops from initially 950 000 g/mol (950K) to 5.000 – 10.000 g/mol. This main chain scission is primarily due to radical processes (see figure below). At an optimal dose, radicals recombine and form molecules with a molecular mass of about 5 000 g/mol. If however the dose is drastically increased, a large number of radicals are produced and undergo crosslinking so that molecules with higher molecular masses are obtained. The PMMA is turned into a negative resist. This effect is depicted in the diagram on the right which shows the gradation curve of a standard process (AR-P 671.05, 490 nm film thickness, 30 kV, developer AR 600-56). High exposure doses convert the resist into a negative resist.

Depolymerisation opon exposure



The main chain of the PMMA is cleaved into many radical fragments

Dose versus acceleration voltage



The sensitivity of a PMMA resist (AR-P 671.05) strongly depends on the acceleration voltage. At 100 kV a major part of the energy passes the resist without any interaction and the resist is consequently less sensitive. At 5 kV however, all electrons are absorbed.