Resist Characterization for 157nm Lithography

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Abstract – A resist characterization experiment was performed utilizing 157nm Vacuum Ultra-violet (VUV) Lithography. A number of older technology resists such as MXP8, APEX-E, and UVIII were placed in the beam path of a Lumonics Series 700 fluorine excimer laser and subjected to timed exposures on the tool. The features were then developed in a low normality CD26 developer and characterization curves for each of the resists were plotted. Through the experimentation it was found that each of the three resists investigated was able to clearly demonstrate imaging qualities at 157nm. The contrast curves of the MXP8 and APEX-E resist indicate that they may have the characteristics to be used as early negative resists at 157nm, while the Shipley UVIII 248nm resist demonstrated both positive and negative characteristics due to competing mechanisms within the resist.

I. INTRODUCTION

As the demand for semiconductor devices continues to exponentially rise in this technology driven society, the geometry sizes of the devices must follow the downward shrinking spiral to compensate for the increased transistor densities on the chip. This continual reduction in feature geometry has been made possible primarily by phenomenal advances in the field of lithography. Conventional lithography has been able to push through many of the assumed optical limits with the integration of highly unconventional ideas that have proven to be very useful. Projection lithography at 157nm, up until this point, has always been one of these assumed unconventional ideas that would never make it into production. Numerous problems with the construction of a viable laser source and the transmissive quality of most production mask and substrate materials at 157nm have prevented its inauguration into high volume manufacturing. However, recent developments in mask making, especially the introduction of calcium fluoride instead of fused silica, as well as the commercial availability of high volume sources have made 157nm a very attractive transition for lithography. Lithography at 157nm holds the key to the expansion of optical lithography to sub-100nm devices and probably even into the 50nm realm (see figure 1), but its infancy lends itself to requiring more substantial characterization.

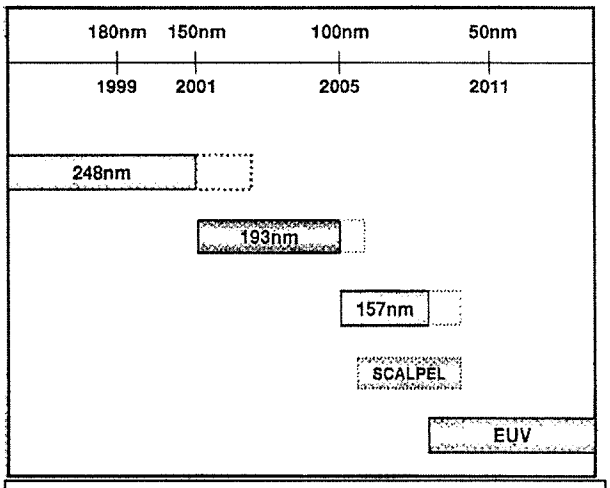


Figure 1: Technology Roadmap (DRAM-half pitch)

II. BACKGROUND

In 1998, RIT's 193nm ArF Lumonics Series 700 excimer laser was converted into a 157nm F_2 excimer laser (see figure 2). This provided a viable and adequate source to be used in a resist characterization study at 157nm lithography. Lithography at 157nm offers several advantages over conventional lithography at 248nm and

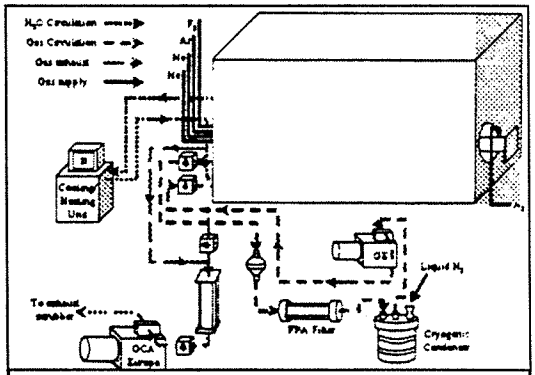


Figure 2: General setup of RIT's laser

193nm. The shorter wavelength introduces an inherent resolution enhancement, while the technology itself is a natural extension to current lithographic processes, in that it uses excimer lasers, refractive optics, and transmissive masks. The primary enhancement of going to the much shorter wavelength of 157nm also provides for a number of disadvantages that may slightly inhibit the desired transition to the new technology. At extremely short wavelengths such as 157nm, the resist thickness begins to approach the total focal plane depth of the optics. This factor combined with desired high numerical aperture values lead to an overall reduction in the depth of focus at 157nm, therefore very thin imaging layers are needed for single layer processing.

The extreme wavelength of the source introduces certain absorption problems with conventional resists as well. Many hydrocarbon polymers (see figure 3) appear to absorb too much of the radiation even when the film thickness is kept to less than 100nm. Thusly, new techniques must be developed to deal with surface imaging. The resists that were investigated throughout this research were MXP8, UVIII, and APEX-E. The resists were either thinned down beyond conventional means (500-1500Å) in order to create ultrathin thicknesses or they were tested at their standard coat thickness at 4000rpm. This shallow thickness allows for the exposure energy of the F_2 laser to penetrate the resist without the energy being wasted by absorption in only the top region.

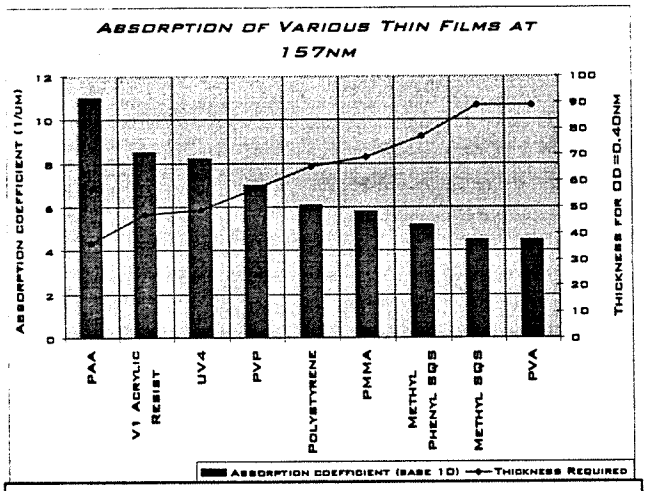


Figure 3: Absorption of various thin films at 157nm

At this point in time, no commercial resists have been created in industry that can successfully utilize the 157nm wavelength for production. In order to demonstrate imaging capability at this wavelength, a new and innovative resist process must first be researched and developed. However, instead of relying upon manufacturers to develop a brand new resist design, a number of resists employed in older technologies were investigated in this experiment through the use of ultrathin resist coatings and top surface imaging (TSI).

One other disadvantage of the transition to 157nm is that traditional fused silica masks are too absorptive at 157nm, and cannot be used for this experiment. Calcium fluoride is being used as a substitute in industry, but due to complications in fabrication, it was not be used as a mask in this experiment. Therefore a hybrid reticle consisting of a completely reflective, aluminum hardmask was used to effectively block the radiation in the unexposed regions.

III. EXPERIMENT

Before any type of characterization of the laser began, the optimal settings of the laser were investigated using the initial research of the laser conversion as a starting point. The optimal gas fill settings found for the laser were set at 85mbar of buffered F_2 with the Helium introduced at 3500mbar and then evacuating the system to around 3200mbar, and ran at 37.6kV and 50pps. This gas mixture provided a substantial amount of lasing with a minimal amount of arcing in the system. Voltage arcing tends to damage the electrodes in the laser. The laser spectrum was then verified through the use of a phosphor detector, Yitrium oxide doped with Europium that had been previously suspended in isopropanol and coated on the inside of a blank glass mask. This is necessary due to the fact that there is no available detector at RIT that would not become damaged at the fluorine excimer's high-energy wavelength.

In order to prepare the resists for exposure in the beam path, each of the resists was thinned out to different dilutions and then coated onto wafers in order to determine which thicknesses were possible and which could be used in the experiment. Prior to coating on the hand-spinner, the wafers were dehydration baked at 120°C for two minutes to remove any excess moisture and then surface primed with HMDS at 3500rpm for one minute. The resists were then coated using a coat recipe at 4000rpm and soft baked at 120°C for three minutes. The excessively high softbake step was utilized to help eliminate as much solvent as possible leaving only the resist polymers to crosslink in the exposure system. Table 1 gives the resist coat thickness for each dilution as well as the modified refractive index (calculated using the Cauchy coefficients) that was necessary for accurate measurement on the Nanospec.

Once the thicknesses were measured on the Nanospec and recorded, the wafers were then scribed into small pieces. Breaking the wafers up is a necessary step due to the fact that there is no optic setup on the excimer laser

Table 1: Resist Thickness and Refractive Index data

Resist	Dilution	Coat Thickness (4000rpm)	Refractive Index
MXP8	None	1939Å	1.589
	1:1	1900Å	
	1:2	1209Å	
	1:2.5	920Å	
	1:3.5	485Å	
APEX-E	None	6358Å	1.5692
UVIII	None	6570Å	1.549
	1:1	2193Å	
	1:2	1614Å	
	1:3	942Å	

and there is no wafer stage, but the wafers must be somehow placed into the exposure beam path. This was accomplished by designing and fabricating a modified wafer chuck (see figure 4), constructed of PVC piping and a glass mask blank. The addition of the N_2 inlet and outlet are necessary so that a nitrogen purge may be introduced

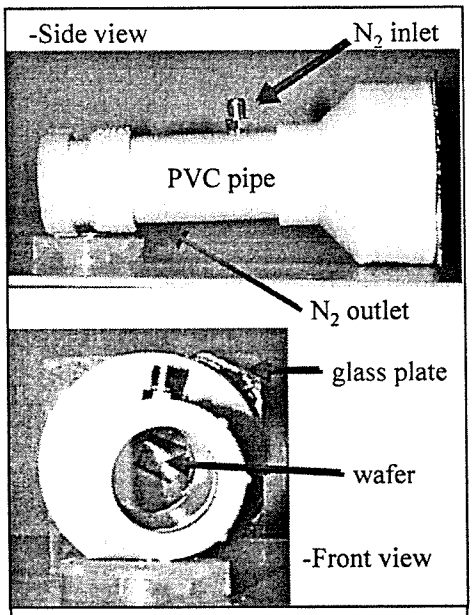


Figure 4: Photo of wafer chuck

into the exposure path to remove any hydrocarbons and oxygen that may absorb the 157nm radiation.

The pieces of the wafers were then covered in an aluminum hardmask and placed directly onto the glass plate using adhesive on the backs of the wafers. Each of the resists was then subjected to timed exposures on the laser and then developed in a low normality CD26 developer to bring out the features.

Prior to developing the Shipley 248nm UVIII resist, however, an additional two-minute post-exposure bake at 120°C was employed in order to activate the chemically amplified resist reaction.

IV. RESULTS AND CONCLUSIONS

Once all of the thickness measurements for each resist were finally performed and the data collated, it was placed into Microsoft Excel for graphical analysis. It could be seen through the use of the characteristic curve plots that the most frequent exposure mechanism for the resists was of a negative nature. This would be due to the high-energy 157nm wavelength crosslinking the polymeric compound in each of the resist systems. All three of the resists exhibited this negative nature with a dose to gel or a timed exposure to gel, while the very thick (~6500Å) UVIII resist exhibited positive resist characteristics.

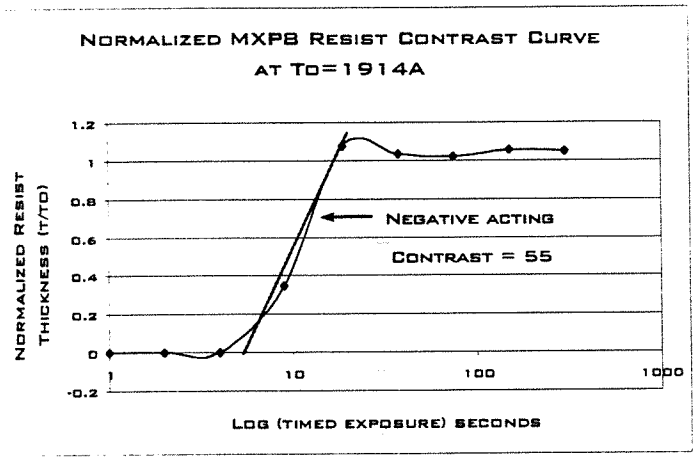
The characteristic curves (see graphs 1-4 on next page) were each plotted similarly to conventional lithographic means, however, without a true dose detector, the real exposure dose could not be found. This leaves the graphs with a normalized thickness of the resist as a function of the log of the timed exposure in seconds. This does not present any real issues in terms of characterizing the resists, but it does, however, leave the contrast or gamma values calculated from the graphs as only comparative values between the three resists. These gamma results cannot be treated as conventional contrast values until they are re-calculated when the exposure dose of the excimer laser can be found.

Both the MXP8 and APEX-E demonstrated very successful negative resist qualities with distinctive exposures to gel and steep on and off contrast curves. The APEX-E had the highest gamma of 301 with about a 200Å increase in thickness after exposure due to crosslinking. All of the values from the characteristics curves are summarized in table 2 below.

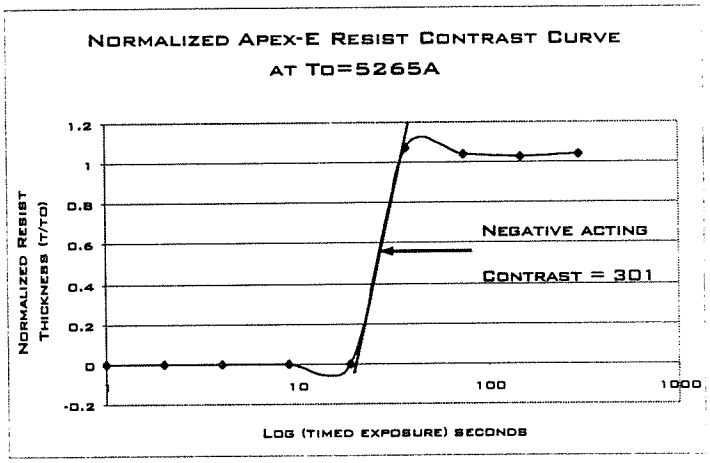
Table 2: Summary of Characteristic Curve data

Resist	Gamma	Thickness Loss/ Gain	Action	Exposure to Gel/Clear (sec)
MXP8	55	+86Å	Neg.	9
APEX-E	301	+210Å	Neg.	18.8
UVIII	154	+130Å	Neg.	9
UVIII	-12	-527Å	Pos.	300

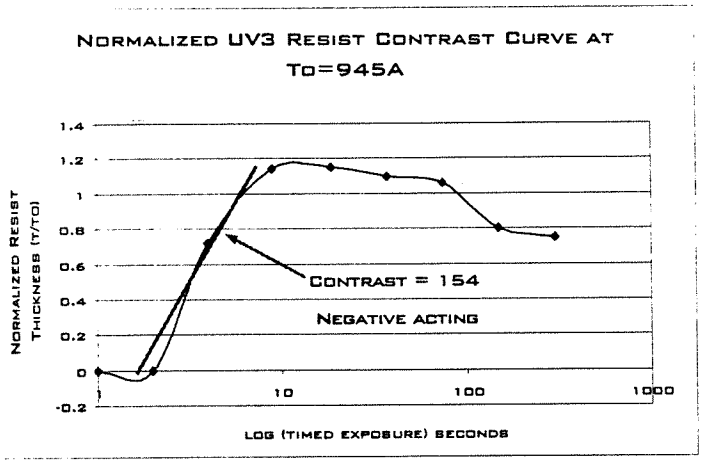
Graph 1: Normalized MXP8 Resist Contrast Curve



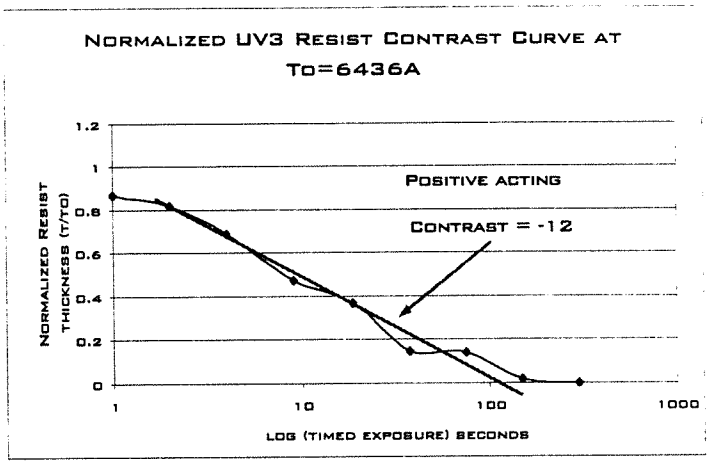
Graph 2: Normalized APEX-E Resist Contrast Curve



Graph 3: Normalized UV3 Resist Contrast Curve (Thin)



Graph 4: Normalized UV3 Resist Contrast Curve (Thick)



It is interesting to note the results obtained for the UVIII resist. At very thick resist coatings of around 6500Å, the chemically amplified resist attempted to act as a positive resist, but fell short with a great deal of scumming and a poor overall nature to the characteristic curve. However, at a very thin coating of around 945Å, the resist attempted to take on negative characteristics with a very short dose to gel of about nine seconds. This can be understood to be competing mechanisms within the resist. On one hand, the chemical amplification is a positive acting mechanism trying to use the exposure energy to rapidly dissolve the exposed regions, while at the same time some crosslinking of the polymer is happening in the same regions. This creates the lackluster appearance for both characteristics curves.

In conclusion, lithography at 157nm will definitely be the next feasible technology node for exposure systems. However, new resists or processes may need to be developed in order to compensate for the current lack of useable resists in manufacturing. Single layer resist processing, utilizing ultrathin resists, may become possible, but certain constraints may be introduced such as a higher susceptibility for defects and problems with current metrology tools. A more feasible approach for production may be the use of a bilayer or silylation schemes that involves thin imaging layers on top of a thicker planarizing layer and a dry etch stop such as in the DESIRE process. Either way, 157nm lithography will help guide microlithography into the sub-100nm realm.

V. REFERENCES

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VI. ACKNOWLEDGEMENTS

The author would like to acknowledge Dr. Bruce Smith for all of his support and guidance throughout the course of this experiment, as well as Dr. Santosh Kurinec and Professor Karl Hirschman for their additional advice, and lastly to Richard Battaglia for all of his technical support.

Christopher Bolton, originally from Monroeville, PA, received a B.S. in Microelectronic Engineering from Rochester Institute of Technology in 1999. He attained co-op experience at Intel Corporation in Chandler, Arizona, in the DUV Lithography group as well as in the Process Integration group.