Reducing bottom anti-reflective coating (BARC) defects: Optimizing and decoupling the filtration and dispense process

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ABSTRACT

Semiconductor device manufacturing is one of the cleanest manufacturing operations that can be found in the world today. It has to be that way; a particle on a wafer today can kill an entire device, which raises the costs, and therefore reduces the profits, of the manufacturing company in two ways: it must produce extra wafers to make up for the lost die, and it has less product to sell.

In today's state-of-the-art fab, everything is filtered to the lowest pore size available. This practice is fairly easy for gases because a gas molecule is very small compared to the pore size of the filter. Filtering liquids, especially photochemicals such as photoresists and BARCs, can be much harder because the molecules that form the polymers used to manufacture the photochemicals are approaching the filter pore size. As a result, filters may plug up, filtration rates may drop, pressure drops across the filter may increase, or a filter may degrade. These conditions can then cause polymer shearing, microbubble formation, gel particle formation, and BARC chemical changes to occur before the BARC reaches the wafer.

To investigate these possible interactions, an Entegris® IntelliGen®2 pump was installed on a TEL Mk8™ track to see if the filtration process would have an effect on the BARC chemistry and coating defects. Various BARC chemicals such as DUV112 and DUV42P were pumped through various filter media having a variety of pore sizes at different filtration rates to investigate the interaction between the dispense process and the filtration process. The IntelliGen2 pump has the capability to filter the BARC independent of the dispense process. By using a designed experiment to look at various parameters such as dispense rate, filtration rate, and dispense volume, the effects of the complete pump system can be learned, and appropriate conditions can be applied to yield the cleanest BARC coating process. Results indicate that filtration rate and filter pore size play a dramatic role in the defect density on a coated wafer with the actual dispense properties such as dispense wafer speed and dispense time playing a lesser role.

Keywords: ArF, KrF, bottom anti-reflective coating, BARC, coating, photolithography, defects, filtration, dispense

1.0 INTRODUCTION

Integrated device manufacturers (IDMs) are extremely critical about defects such as post-etch or post-coat. Any defect could render the device unusable, which would cause a financial loss for the manufacturers. It is nearly impossible to have zero defects on a wafer just from the sheer number of steps involved with the manufacturing process, so IDMs embark on a campaign to reduce defects to the absolute minimum. Reducing defects is another non-trivial problem because of the possible factors that play a role. For example, BARC coating defects are affected by the dispense process, examples are, dispense wafer speed, dispense volume, and dispense rate; as well as the manufacturing process which include cleanliness of the materials and filtration process. Typically, IDMs in this case would implement an extra filtration step at the point of dispense on the coater module, and modify the coat process to minimize defects of the BARC.

When the coat track called for a pump dispense, previous models of the point-of-use pumps would push fluid through the filter during the actual dispense on the wafer. This would mean that the fluid was filtered at the same rate as the dispense rate of the fluid. This is not a concern for larger pore size filters. However, with todays filtering processes use pore sizes of 0.01 μm or less, possible problems can exist. Some of these problems could be excessive pressure drop across the filter, causing gels to pass through the filter, or the fluid dispense would start badly by dripping rather than a solid stream. Pump models have been designed now to separate the filtration and dispense process. These pumps are simply two pumps installed together, the filtration pump will feed a small reservoir for the dispense pump, that is refilled

while the pump is not dispensing on the wafer. This will allow the filtration pump to filter the fluid at a much different rate than that of the dispense. This can then allow the use of extremely small pore size filters to remove the smallest contaminant as well as keeping the pressure drop low across the filter, increasing the filtration efficiency.

With added flexibility of the pumps comes another factor that the IDM must account for during the dispense process setup. Namely, what is the most efficient filtration rate given a particular filter pore size? Does the filtration rate depend on the fluid? A designed experiment, using various BARC materials were subjected to various filtration rates and filters to begin answering these questions. Results indicate that filtration rate and filter pore size play a dramatic role in the defect density on a coated wafer with the actual dispense properties, such as dispense wafer speed and dispense time playing a lesser role.

2.0 EXPERIMENTAL

BARC's with different molecular weights ranging from 10,000-100,000 Daltons were selected for these tests; they were DUV112, ARC®29A, and DUV42P. The testing was accomplished using a Entegris IntelliGen®2 pump attached to a TEL Mk8™ coat track. A KLA-Tencor 21xx defect tool was used with a 0.39-μm pixel size to count defects on the coated wafers. The testing plan involved two steps. The first was to install a 0.05-μm UPE filter on the pump along with one of the BARC's. Then, run a designed experiment which, when analyzed, identified the coating process with the lowest defect density. The second part of the testing plan was then replace the filter with other filters and then change jusy the filtration rate while keeping the dispense process constant. It was assumed that the filtration process and the dispense process could be treated as if the processes were independent of each other, which according to the modeling was a correct assumption.

The designed experiment utilized four factors in a response surface design, these were filtration rate, dispense volume, dispense time, and dispense wafer speed. The ranges chosen for each factor are listed in Table 1a. Table 1b; lists the filters and filtration rates used for the second part of the testing plan.

3.0 RESULTS AND DISCUSSION

3.1 Dispense Process

For the three BARC materials it was assumed that each material would have a different optimum dispense process, and so each BARC material was ran under the dispense process DOE. The modeled results indicated just that. For DUV112 and DUV42P, which have a similar chemical makeup but different molecular weights, the dispense wafer speed was required to be high, around 4000 rpm, while the ARC29A coating needed a wafer dispense speed of around 3000 rpm. The dispense time and dispense rate of the BARCs were weak factors and had negligible effect on the defect density of the coated wafers except for DUV112.

It was assumed that the filtration and dispense process would be independent of each other in the DOE modeled results such that:

$$Defect\ Density(WS,DT,DV,FR) = \sum_{i,j,k=0}^{2} a_{ijk} WS^i DT^j DV^k + \sum_{n=0}^{2} b_n FR^n$$

$$WS = Wafer\ Speed$$

$$DT = Dispense\ Time$$

$$DV = Dispense\ Volume$$

$$FR = Filtration\ Rate$$

This relationship would allow further testing of filter types and pore sizes and change the filtration rate and just affect the defect density of the wafers. In all three BARC's, the assumption held true and the filtration process was independent of the dispense process. For DUV42P, the DOE indicated the filtration rate for the 0.05-μm UPE filter should be high to achieve the lowest defect density, which is contrary to what one would expect. The ARC29A results indicated the trend would be a lower defect density if the filtration rate was slow. Filtration rate for DUV112 was considered a weak factor, with a slight trend toward high filtration rates yielding a lower defct density.. The pareto charts for the different BARCs are shown in Figure 1. Figure 2 displays the prediction results from the statistical

software program, JMP. The interpretation of these results is thought to be how the polymer in its liquid form is wrapped on itself. If the polymer strand is long or has a tendency to fold onto itself into a very large volume, it would require a high-pressure drop across the filter to force this material through the filter media by stretching the polymer strand out and allowing it to pass through. Conversely, if the polymer strand is short or does not tend to fold on itself, then it would require a lower pressure drop to force it through the filter media.

3.2 Filter Testing

Once the coating process was identified, the second part of this test could be undertaken. Here the coating process was kept constant as the filter media, pore size, and filtration rate varied. This test would help identify any trends, if any, which occur with filter media, pore size, or filtration rate. Once the data was collected and analyzed, it was found that the trends are BARC specific and filter specific.

Trends found for DUV112 was identified as pore size and possibly filtration rate. Smaller filter pore size directly trended with a lowering of the defect density, irrespective of the filtration rate, as shown in Figure 3. This indicates that the molecular weight of DUV112 or the shape of the polymer in the solvent allows the material to flow easily through smaller pore sizes. The filtration rate dependence for DUV112 may be a weak factor or was not as well defined with only a few wafers coated at each filtration rate. As shown in Figure 4, the 0.1-mL/sec filtration rate appears to be a higher defect density than the other filtration rates.

Filter media plays a surprising role with DUV42P as shown in Figures 5 and 6. Here the 0.02-μm PCM filter creates the lowest defect density compared to the other filters. DUV42P is a high molecular weight BARC, since this would be a very large molecule, it would indicate that the PCM type media, which has a different surface chemistry than UPE but is made out of the same material, allows DUV42P to move through the filter much easier. The filtration rate data also appears to indicate a trend of increasing the filtration rate and a reduction in defects. These data bolsters the idea that the pressure drop is a factor in lowering defects in DUV42P, and that an optimum pressure drop is required to keep the defects to a minimum. By keeping the filtration rate high, the polymer shape can be deformed to push through the filter.

4.0 CONCLUSIONS

Pumps that allow the filtration and dispense processes to be decoupled from each other allow much more flexibility to reduce defects on wafers. This gives IDMs more options to reduce defects and increase yield. The disadvantage is that more process setup is required to define the optimum process. New ideas that have come about with this work is that the filtration rate is independent of the dispense process allowing simple and straightforward testing of new filters or media. Also, reducing defects by reducing the filter pore size may not always be a correct assumption, with new surface modifications available for the filters; a situation that does not reduce pore size could be used to reduce defects. This allows high molecular weight materials or large molecule materials to be used in the latest generation BARCs or photoresists, giving chemical manufactures flexibility to tailor attributes to particular needs such as optical properties or coating performance.

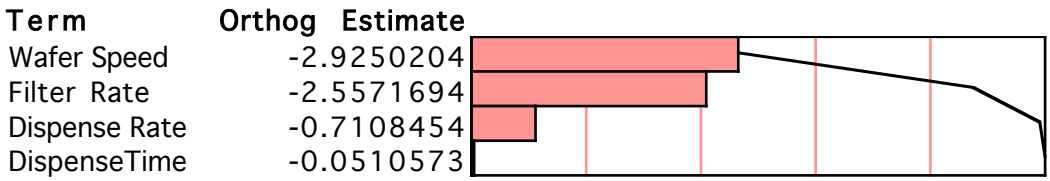
(a)

DOE Factors	Range
Filtration Rate	0.1 - 4 mL/sec
Dispense Wafer Speed	500 – 4500 rpm
Dispense Rate	0.5 – 2 mL/sec
Dispense Time	1 – 2 sec
BARC Molecular Weight	DUV112 (low), ARC29A (medium), DUV42P (high)

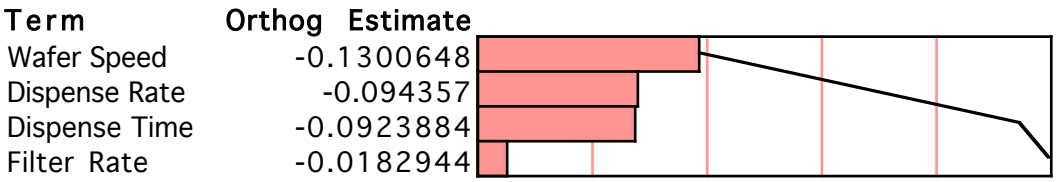
(b)

Filters used	Filtration Rate
0.05 μm UPE (DOE setup)	0.1 – 4 mL/sec
0.02 μm UPE	
0.02 μm PCM	
0.01 μm UPE	

Table 1. (a) DOE setup, and (b) filter setup for test plan.



(a)



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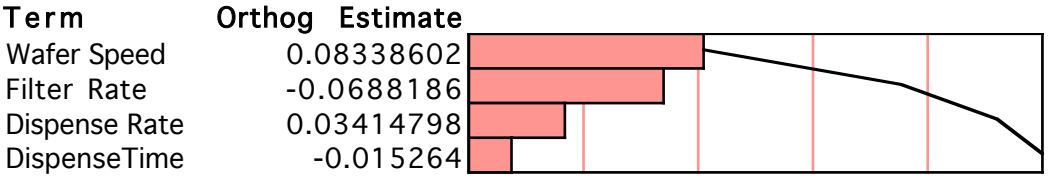
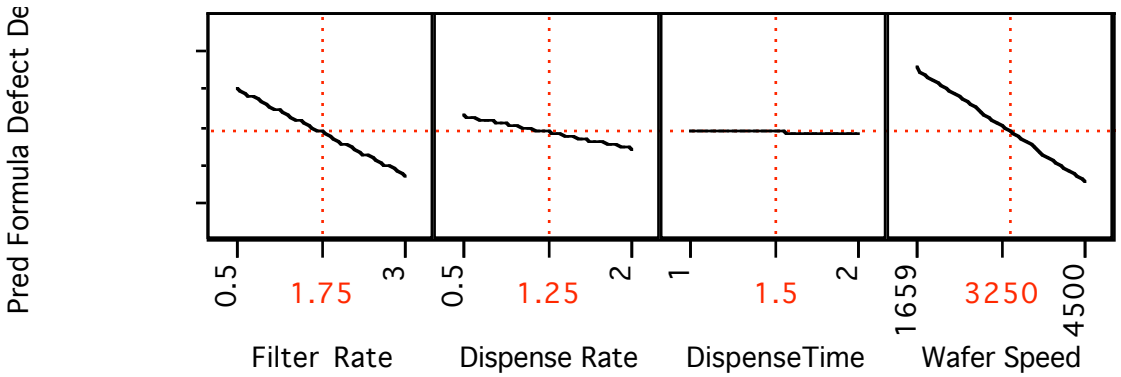
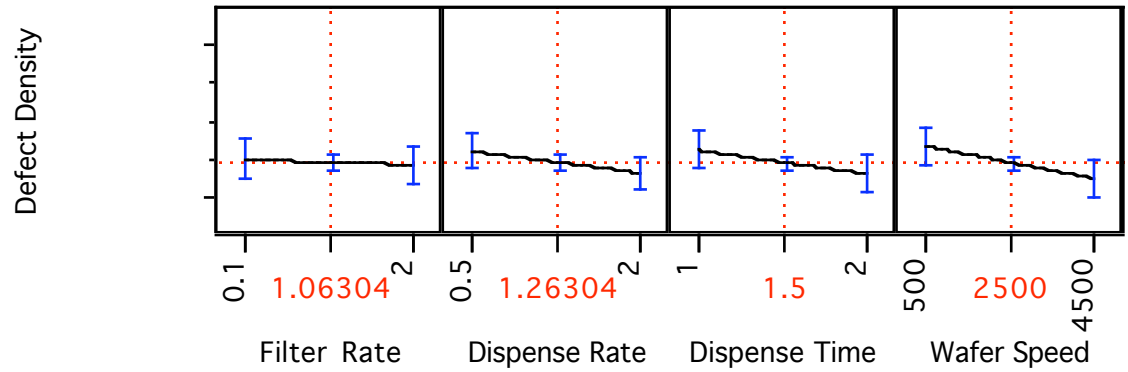


(c)

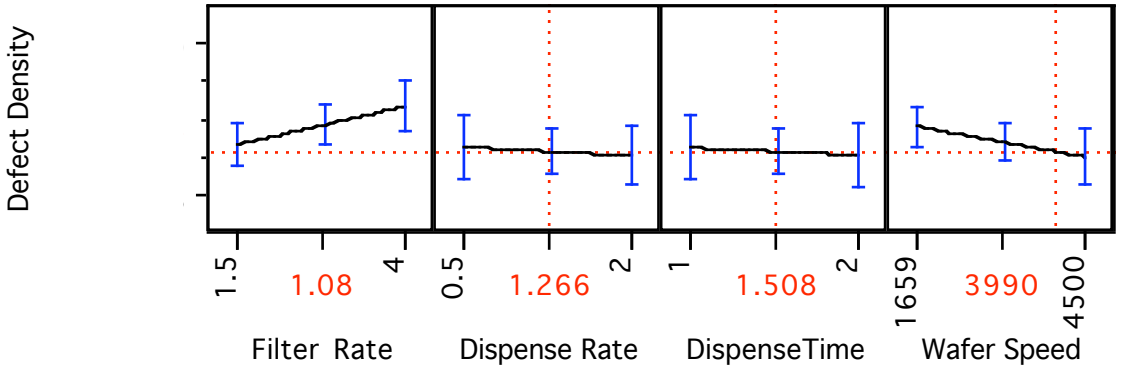
Figure 1. Pareto chart of DOE factors for (a) DUV42P, (b) DUV112, (c) ARC29A.



(a)



(b)



(c)

Figure 2. Prediction plots for (a) DUV42P, (b) DUV112, (c) ARC29A.

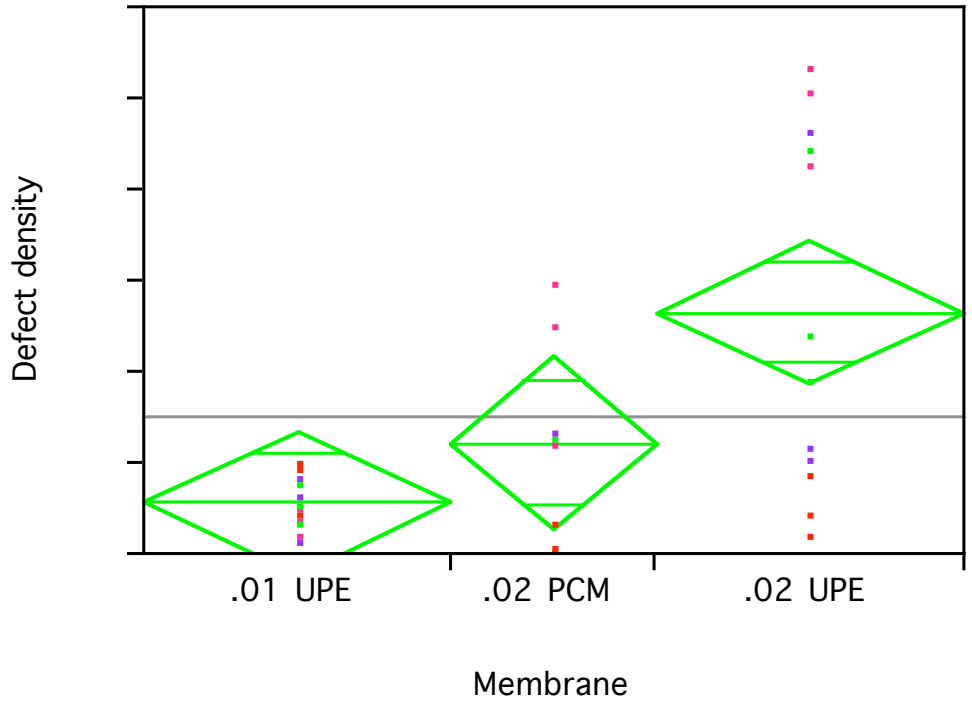


Figure 3. Defect density dependence of filter media for DUV112 (includes all filtration rates).

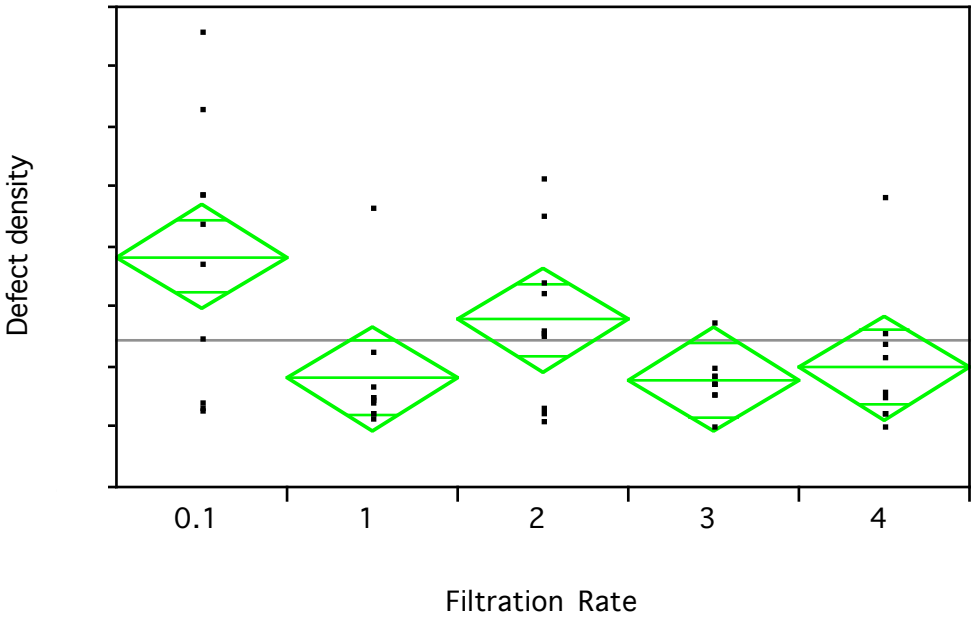


Figure 4. Defect density of DUV112 with changing filtration rate (includes all filter media).

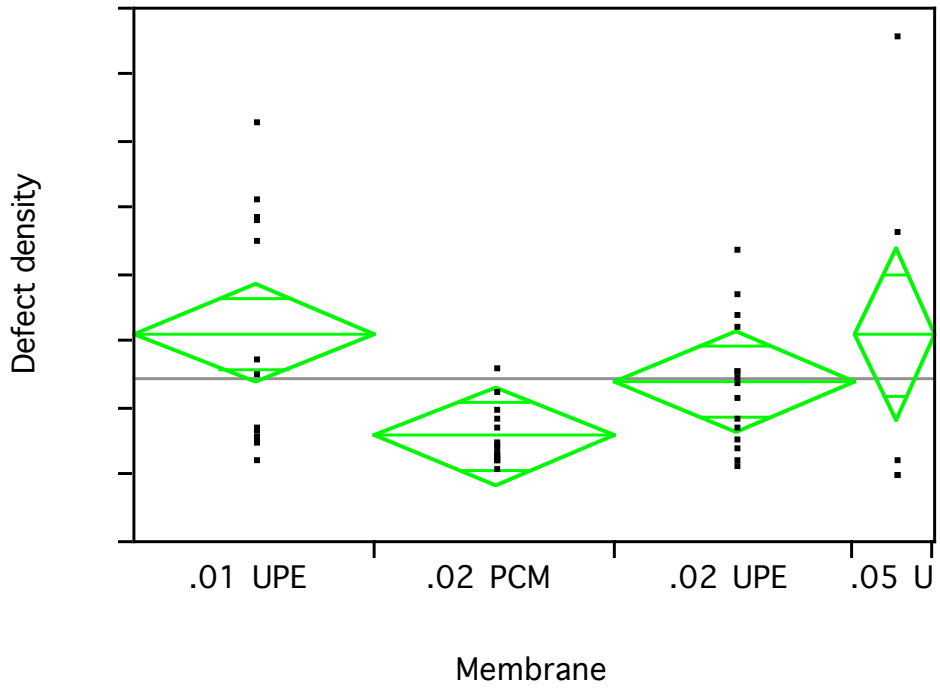


Figure 5. Filter media dependence on defect density with DUV42P (includes all filtration rates, 0.05-μm defect density from DOE model).

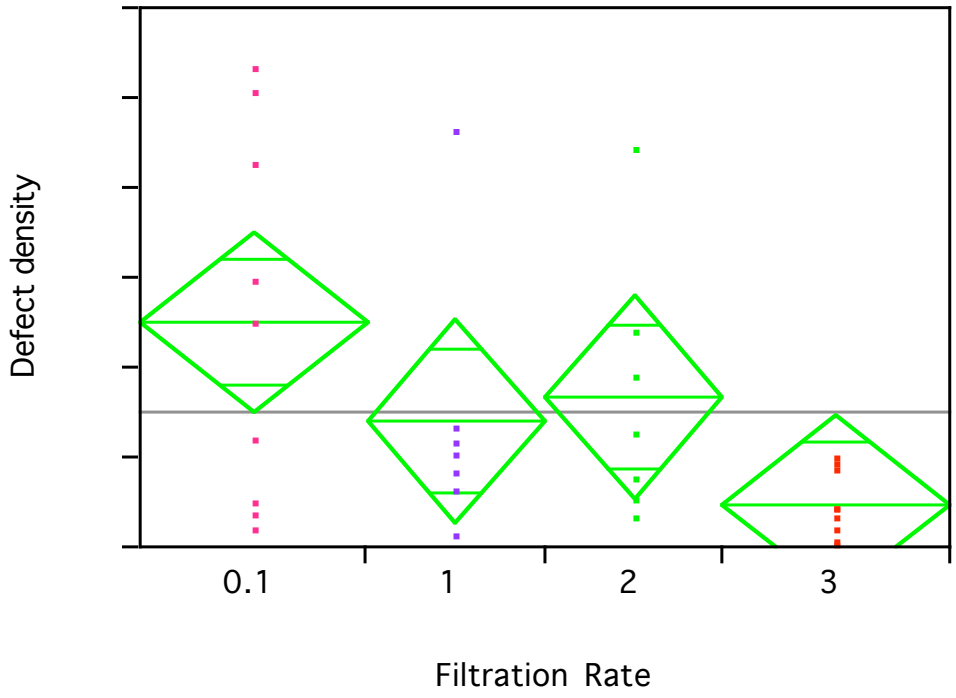


Figure 6. DUV42P filtration rate dependence (includes all filter media).