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Simulation of Vacuum Characteristics of High Vacuum System Modelled by VacCAD

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Abstract

In this paper, we simulated three different HV systems and analyzed of each vacuum characteristics by VacCAD modelling. In each of modelled vacuum systems, selection of chamber materials, combination of rough pump with high vacuum pump and conductance of roughing line (diameter and length) were proposed as system variables. In the modelling of chamber materials, the pumping times to ultimate pressures of different chamber materials (stainless steel, aluminum) were compared by the variations of chamber volume. In this model, the effects of outgassing dependent on the chamber materials was also simulated and aluminum was estimated to optimum chamber materials. It was also obtained that modelling of vane and roots pump with diffusion pump and diameter, length of 50×250 [mm] roughing line were characterized as optimum variables to reach the ultimate pressure of 10E-7 [mbar] most effectively. Optimum design factors for vacuum characteristics of modelled vacuum system were achieved by VacCAD simulations. Feasibility of VacCAD as vacuum simulator was verified and applications of VacCAD expected to be increased to fields in vacuum needed.

Keywords: *VacCAD, Simulation, Vacuum system modeling, Vacuum characteristics, Optimum design factor*

1. Introduction

Even though the future of Moore's law is insecure, the demands of semiconductors are getting increased. Therefore, cutting edge facilities of semiconductor process would have been required continuously. Especially the extreme ultra violet (EUV) lithography is expected to be leading technology in microelectronic fabrications. As EUV process needs to be operated in high or ultra high vacuum range, the creation and managements for high quality vacuum should be established sustainably. Therefore, to achieve the ultimate vacuum and maintain the high quality vacuum consistently, simulation of vacuum characteristics in modelled vacuum systems would be effective and helpful to optimize the performances of vacuum system. In this study, one of commercial vacuum simulators, VacCAD, was introduced to evaluate the feasibility of vacuum simulations based on the various modelling factors provided by VacCAD. Three different models of

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high vacuum system were established and simulated. First model was based on the variables of chamber materials. By comparison of the simulation results of chamber materials with aluminum and stainless steel, aluminum showed 14.3 times shorter pumping time to reach 10E-7[mbar]. So aluminum was verified to suitable chamber material for 1.0E-7 $[mbar]$ pressure range. Second model was simulated to achieve optimum pump combination in pumping time for 1.0E-7$[mbar]$. As the variable of rough pump, vane pump and vane with roots pump were considered. Vane with roots pump showed 4 times faster to reach the rough vacuum of 9.0E-3 $[mbar]$. Turbomolecular pump (TMP), cryo-pump, diffusion pump were employed as high vacuum pump. Among these three pumps, diffusion pump was fastest to reach ultimate pressure 1E-7$[mbar]$. But, as ultimate pressure of cryo-pump had been lower 1E-4$[mbar]$ than diffusion pump, it was indicated that cryo-pump would be better to reach the below 1E-7$[mbar]$. In case of model three, it was simulated to find optimum conductance dimension of roughing line to reach the 1E-7$[mbar]$ range. Simulation results of three different models were obtained as follows. Aluminum as chamber material was optimum factor due to low outgassing rate. Vane with roots pump and diffusion pump or cryo-pump concerning ultimate pressure were optimum combination for high vacuum system. And, the wider diameter and the shorter length were optimum condition for better conductance of roughing line. Therefore, the obtained simulation result showed the feasibility of VacCAD as vacuum simulator.

2. Simulations

2.1 VacCAD 1.0 simulation

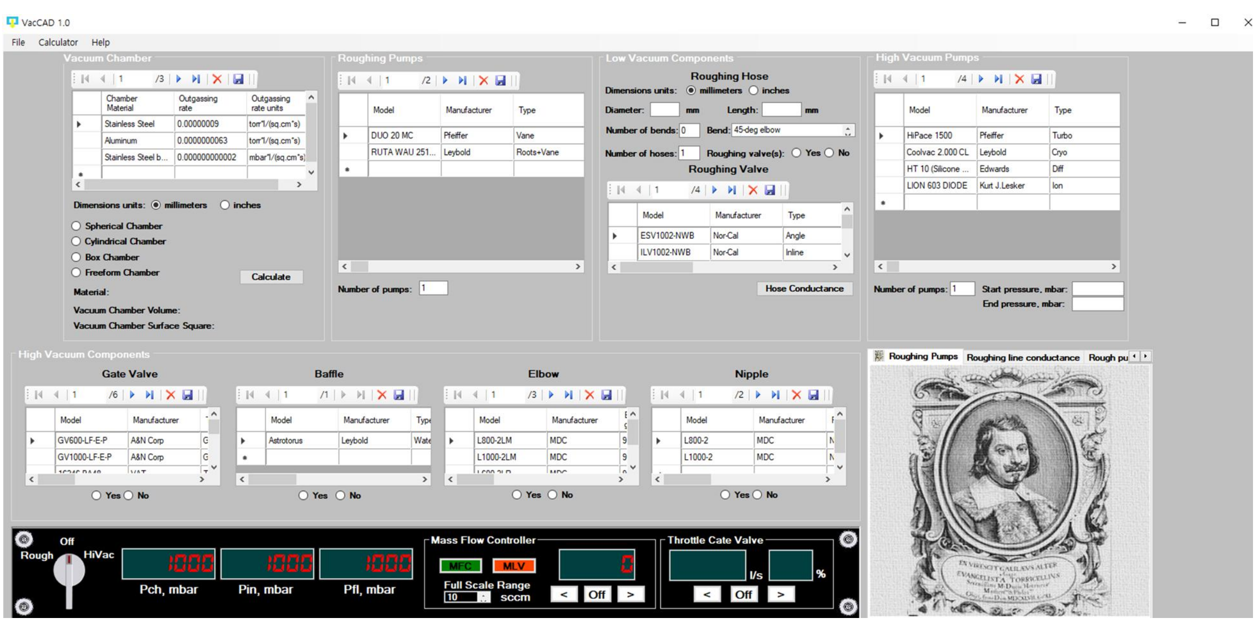

Figure 1. Main variables panel of VacCAD

Each panel was available for users to simulate certain vacuum conditions. If variables were chosen among the list of panel, the chosen variable is shown right below the panel. With setting up of all the specific vacuum conditions, when a user clicked a button at the left-bottom side from ‘off’ to ‘rough’ or ‘high vacuum’, the simulation data would be illustrated as a form of curved graph on a picture of scientist, at the right-bottom side. In addition, the result data could be achieved both as a curved graph or text file so that more specific information could be acquired. Also, by controlling mass flow controller and throttle gate valve, more variables could have been added but those were not considered in this simulation. Furthermore, extra variables could be edited for each control panel. Therefore, high expandability and practicality of VacCAD as simulator was verified.

2.2 Simulation modeling

Three high vacuum system were modelled to estimate the time to reach 10E-7[$mbar$]. For each model, as indicated in Table.1, three variables were chosen as system variables of proposed high vacuum system. If there's no additional mention, fixed variables (stainless steel-cylindrical-65.4[l] (volume of chamber) -vane pump- 50 and 500[mm] with roughing hose's diameter and length - 90° elbow standard radius for bend - HiPace 1500 (TMP)) were used for simulation. By comparing time to reach ultimate pressure (10E-7[$mbar$]), optimum design factor was achieved through the suggested high vacuum system.

Table 1. Proposed simulation modelling

(a)

Model No	Chamber shape	Chamber material	Diameter[mm]	Height [mm]	Volume[l]	Surface Area [$sq.cm$]
1	Cylindrical	Stainless steel Aluminum	500	333	65.4	7194
			630	420	130.8	11430
			700	510	196.2	15063

(b)

Model No	Chamber shape	Chamber material	Roughing pump	High vacuum pump
2	Cylindrical	Stainless steel	Vane Vane with Roots	TMP Cryo-pump Diffusion pump

(c)

Model No	Diameter of Roughing hose [mm]	Length of Roughing hose [mm]
3	25	250
	50	500

2.2.1 Simulation of chamber material

In this high vacuum model, three different chamber materials in the vacuum chamber panel, pumping time to ultimate pressure(10E-7[$mbar$]) of stainless steel chamber was measured with aluminum chamber. Rather than comparing single volume, three volumes (65.4, 130.8, 196.2[l]) were compared for the higher reliability. Also, for chamber shape as cylindrical was employed as fixed variable in each simulation.

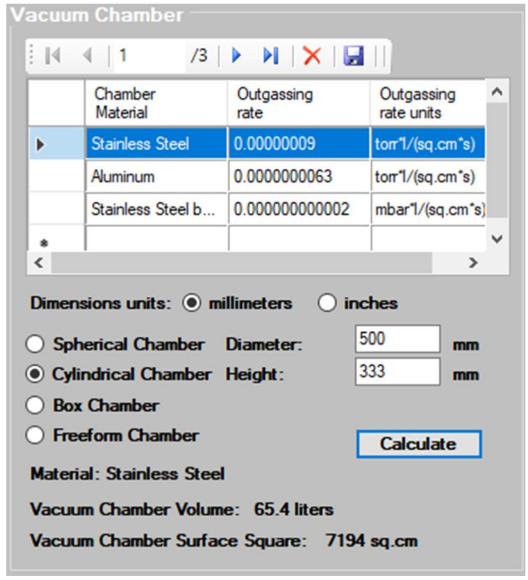

Figure 2. Vacuum chamber panel

In figure 2, one of the most significant factors affected on the ultimate pressure was outgassing. The outgassing rate of stainless steel chamber (6.3×10E-9 $[torr * l / (sq.cm * s)]$) surpassed that of aluminum chamber more than ten times.

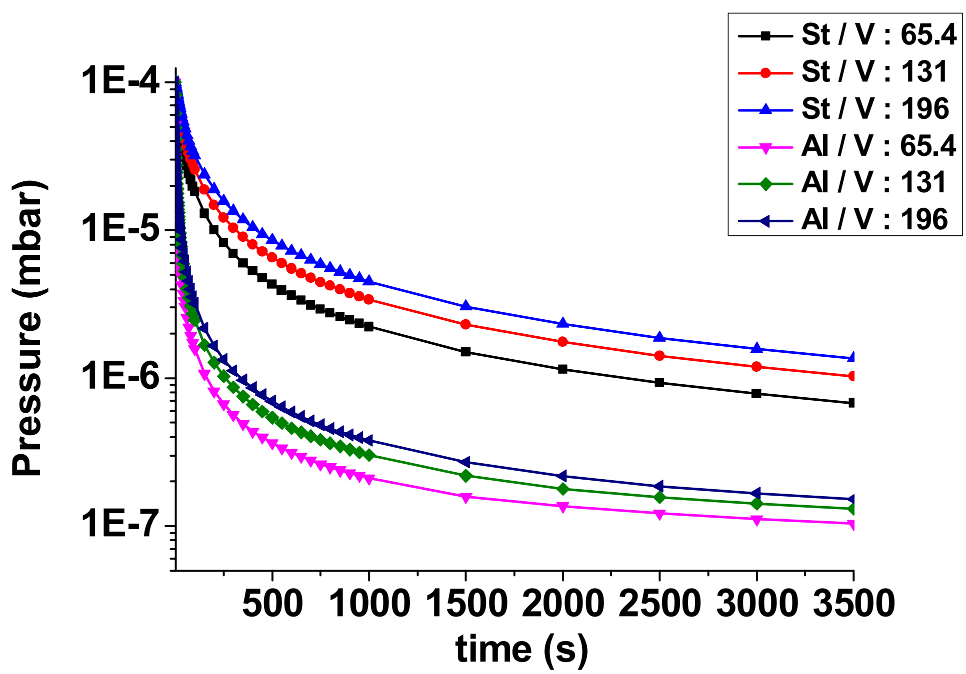

Figure 3. Pumping time of stainless steel and aluminum

Table 2. Pumping times of stainless steel and aluminum chamber

Pressure $[mbar]$ / Time$[s]$	5.0E-05		1.0E-05		5.0E-06		1.1E-06	
	St	Al	St	Al	St	Al	St	Al
V = 65.4 $[l]$	22	1	200	15	400	30	2000	150
V = 130.8 $[l]$	35	3	350	24	700	45	3500	250
V = 196.2 $[l]$	45	4	450	30	900	60	4500	300

Fig.3, table 2 showed the pumping time to high vacuum of stainless steel and aluminum as a chamber material. In stainless-steel, rapid fall of pressure was found between 1E-5 and 1E-6 [mbar] (about 600[s] in time). After that, the pressure change was stabilized quickly. In another case, similar drop occurred until 9E-7 $[mbar]$. In the smallest chamber size, the difference in pumping time that aluminum chamber took shorter to 1.1E-06 $[mbar]$ between two different chamber materials was 13times. The difference became higher as the volume get larger. It was 14 and 15 times for 130.8 and 196.2$[l]$ each. As the volume of chamber got larger, not only pumping time but also the difference of pumping time between two chamber got higher. Therefore, it was demonstrated that influence of outgassing became more dominant factor in larger volume of chamber.

2.2.2 Simulation of pump combination

In modeling of pump combination, comparisons of pumping speed and ultimate pressure that were changed according to pump combination were simulated. The simulation pump types such as mechan ical pump, TMP, diffusion pump, and cryo-pump which were employed in this high vacuum system were typically used in semiconductor processing.

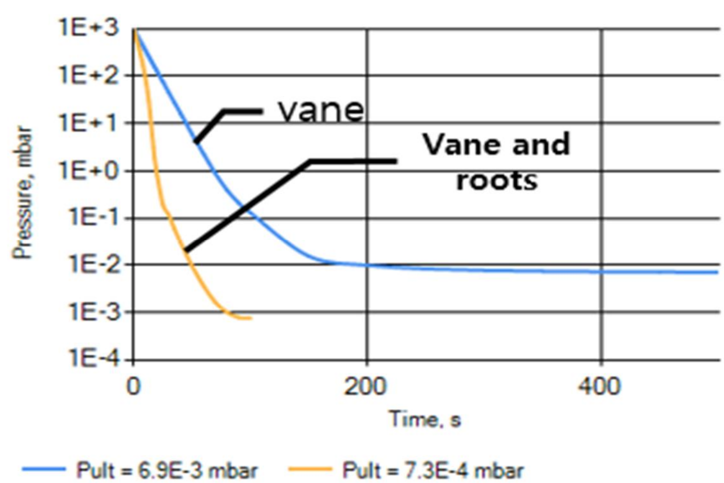

Figure 4. Rough pumping comparison

As illustrated in Figure .4, the difference of pumping time at 1E-2 $[mbar]$ was about 100s which mean that roots with vane pump performed more efficiently. The difference became so huge below 1E-2$[mbar]$

that vane with roots pump had to be considered in that pressure range. And next, it was simulated to compare performance between TMP, cryo-pump and diffusion pump.

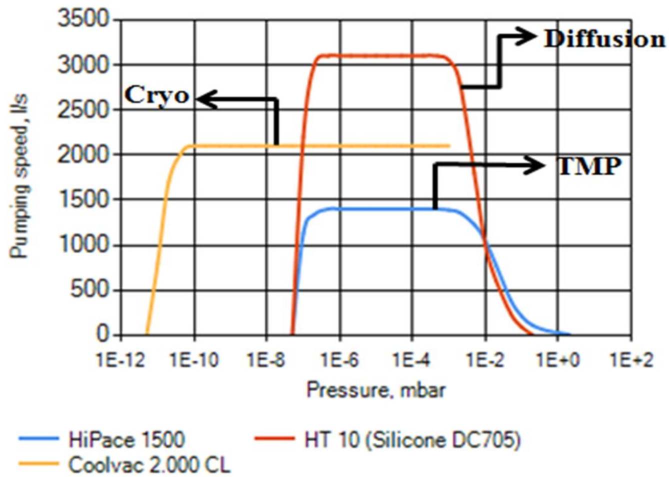

Figure 5. Effective high vacuum pumping speed of vane roughing pump

In Figure 5, the Hipace1500, Coolvac 2000 and HT 10 represented TMP, cryo pump and diffusion pump. Pumping speed of diffusion pump in 1E-3 to 1E-7[$mbar$] range was as fast as twic e from that of the TMP. So, using a diffusion pump instead of a TMP in this pressure range could have reduced the time as much as twice to reach the target pressure of 1E-7[$mbar$]. Below 1E-7 [$mbar$], it was most efficient to use the cryo-pump because as showed in Fig.7, ultimate pressure o f cryo-pump was about 1E-4 [mbar] lower than diffusion pump. However, pumping speed of cryo-pu mp significantly slowed down below approximately 1E-10[$mbar$].

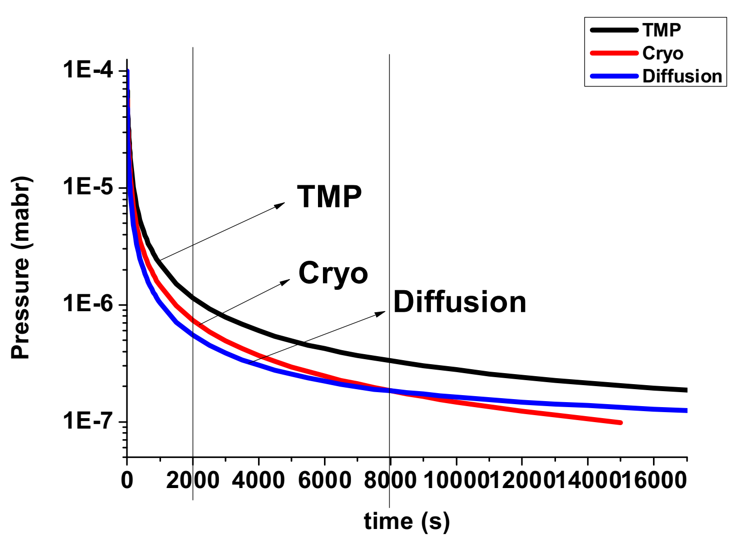

Figure 6. Pumping time of three different high vacuum pump

Depending on the slope of the curve, it was divided into initial, medium, and final. 0 to 2000[s] was the initial section. This was the section where the pressure decreased at fastest rate. In this section, the pump which showed the steepest slope was the diffusion pump and next was cryo-pump, TMP. 2000s to 8000[s]

was a medium section. The slope of all the graphs has been relaxed compared to the initial section. But diffusion pump was still fastest. From 8000[s], however, it was indicated that the pumping speed of the diffusion pump, which had the steepest slope in the initial section, was slower than that of the cryo pump. In other words, cryo-pump performed fastest from this section, not the diffusion pump. At 15000$[s]$, the cryo pump was 9.85E-8$[mbar]$ and the TMP was 2.04E-7$[mbar]$, which implied that cryo-pump already reached the ultimate pressure. Through this model, it was shown that performance of cryo-pump exceeded diffusion pump in pumping time near 1E-7 [mbar] range. In other word, results provided that diffusion pump was fastest below 1E-7 [mbar] and cryo-pump was fastest in higher pressure. Thus, usability of VacCAD was confirmed to reach ultimate pressure more efficiently.

2.2.3 Simulation of conductance in roughing line

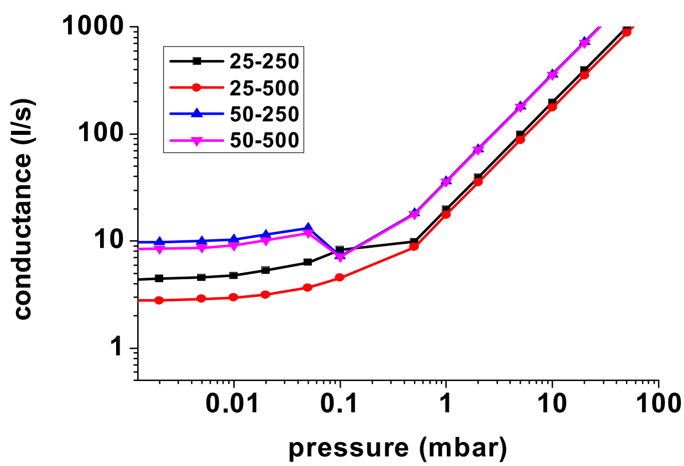

Figure 7. Simulation results of roughing line conductance

Table 3. Simulation results of roughing line conductance plotted as curves in Fig.5.

Pressure $[mbar]$ / Conductance $[l/s]$	1000	100	1	0.1	0.001
Dia 25 - 500 $[mm]$	17578.13	1757.813	17.57813	4.546752	2.78894
Dia 25 - 250 $[mm]$	19721.8	1972.18	19.7218	8.301148	4.356788
Dia 50 - 500 $[mm]$	35738.95	3573.895	35.73895	7.14779	8.413033
Dia 50 - 250 $[mm]$	36239.5	3623.949	36.23949	7.247899	9.710784

In this roughing hose model, comparisons of length with fixed diameter was simulated. When the diameter was fixed with 25$[mm]$, conductance become higher with shorter length of hose. As the 500$[mm]$ length of hose was two times longer from another one, conductance was also expected to as high as double. However, contrary to it, the conductance of 25 and 250$[mm]$ hose was only 1.12 times higher than that of 25 and 500$[mm]$ up to 1 [mbar]. Therefore, conductance was not directly proportional to length of roughing hose in pressure. The lower pressure, the bigger difference. Finally the variation became 1.56 times as pressure went lower to 0.001$[mbar]$. The following comparison was made with a fixed diameter of 50$[mm]$. Likewise conductance was higher with the hose length was 250 than 500$[mm]$. In this case, 50 and 250$[mm]$ line showed 1.16 times higher conductance at 100 and 1$[mbar]$. Interesting behavior was shown between 0.1 and 0.04$[mbar]$. According to table 9, both graphs fluctuated and conductance get higher again. And next, fixed variable in length was analyzed. When the length was fixed with 500$[mm]$, difference of conductance that 50 and 500[mm] hose had been larger was 1.57 times at 0.1$[mbar]$. But after fluctuation of 50 and 500$[mm]$ hose between 0.1 and 0.04$[mbar]$, difference got higher to be 3 times. As the last model, fixed variable of 250$[mm]$ in length was used. The conductance quickly decreased by 0.8$[mbar]$ with showing gap which was 1.9 times higher for 50 and 250$[mm]$. Unlike 25 and 500$[mm]$ hose, there was a section where shorter hose surpass the longers. It was approximately 0.1$[mbar]$. After that, the difference became larger again and it became about twice at 0.001$[mbar]$. As a result of this analysis, the larger the diameter, the higher the conductance in general. It was also expected that length of hose had influenced on conductance but it was verified that the diameter affected conductance more rather than the length. It was concluded that this simulation result would be more valuable especially in the design of vacuum system.

3. Conclusion

From the simulations of three different high vacuum systems, three optimum design factors were obtained as follows. Aluminum chamber was highly superior to stainless steel chamber in pumping time for 1E-7$[mbar]$. As the optimum pump combination, vane with roots pump and diffusion pump was verified to be the highest in pumping speed. It had to be considered that because of lower ultimate pressure of cryo-pump, it should be employed below 1E-7$[mbar]$ range. Shorter length and larger diameter of roughing line hose was demonstrated to be optimum factors from conductance modelling. The diameter of the roughing line was verified to increase conductance more effectively compare to the length of roughing hose. As the applications of vacuum technology become larger and more important particularly in semiconductor industry, more fore-studies based on the results of this simulator are expected to be conducted. Therefore, the possibility of utilization of the VacCAD for the simulation of high or ultra-high vacuum system was verified.

Acknowledgement

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