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Simulations of Effects of Variable Conductance Throttle Valve on the Characteristics of High Vacuum System

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Abstract

Thin film electronic devices which brought the current mobile environment could be fabricated only under the high quality vacuum conditions provided by high vacuum systems. Especially for the development of advanced thin film devices, constant high quality vacuum as the deposition pressure is definitely needed. For this purpose, the variable conductance throttle valves were employed to the high vacuum system. In this study, the effects of throttle valve applications on vacuum characteristics were simulated to obtain the optimum design modelling of variable conductance of high vacuum system. Commercial simulator of vacuum system, VacSim$^{(multi)}$, was used on this investigation. Reliability of employed simulator was verified by the simulation of the commercially available models of high vacuum system. Simulated vacuum characteristics of the proposed modelling were agreed with the observed experimental behaviour of real systems. Pressure limit valve and normally on-off control valve were schematized as the modelling of throttle valve for the constant process-pressure of below 10^{-3} torr. Simulation results were plotted as pump down curve of chamber, variable valve conductance and conductance logic of throttle valve. Simulated behaviors showed the applications of throttle valve sustained the process-pressure constantly, stably, and reliably.

Keywords: *Vacuum system, Throttle valve, Variable conductance, Vacuum simulation*

1. Introduction

Recently, the applications of vacuum technology is indispensable for the cutting edge technologies such as macro and nano engineering. Developments of high-tech products could not be accomplished without the generation of high quality vacuum environments. Highly advanced techniques on the generation, measurements, maintenance of vacuum and evaluation of vacuum system had become an essential for the fabrications of micro electronic devices. Especially, most of the process equipments of IC chips which brought the current mobile environments are the vacuum systems[1,2]. Applications of high performance of vacuum system are expected to be keep growing on next decades. Generally, the manufacturing costs of

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vacuum system are very high and performance characteristics also strongly dependent upon the design modelling of system. Therefore, simulation of vacuum systems based on the design factors is very important to predict the vacuum characteristics and reduce the manufacturing expenses considerably for the optimum system design. Among the vacuum characteristics of process equipment, the reliable sustainability of constant process-pressure should be ensured for the successful process managements. To achieve the reliable constant process-pressure in high vacuum (HV), it is essential to utilize the variable conductance throttle valve on vacuum system. Applications of variable conductance throttle valve on vacuum system has continued to grow with the advance of electronic devices. Even greater demand and more stringent pressure controls are expected to be imposed on throttle valve requirements[3]. In this study, we investigated the effects of throttle valve applications on vacuum characteristics of HV system. The acquired simulation results of the modelled throttle valves suggested the optimum design factors for variable conductance system. Commercial simulator of vacuum system, VacSim$^{(multi)}$, was used on this work[4,5]. Reliability of employed simulator was verified by the simulation of diffusion HV system. Simulated vacuum characteristics of the proposed high vacuum modelling were agreed with that of the experimentally observed behavior of real systems. Based on this verifications, performance of variable conductance throttle valve for the constant process-pressure was modelled and simulated. Pressure limit and normally on-off valves were schematized as the variable conductance throttle valve for constant process-pressure of below 10^{-3} torr. Simulated vacuum characteristics were achieved as pump down curve of chamber, variable valve conductance and conductance logic of throttle valve. Simulation results showed the applications of throttle valve sustained the process-pressure constantly, stably, and reliably. The outgassing effect with fixed process-temperature on vacuum characteristics of throttle valve system was also simulated.

2. Simulations

2.1. Simulation of diffusion pump system

For the verification of VacSim$^{(multi)}$ simulator's feasibility on modelling mechanism, Diffusion pump HV system was modelled in this investigation. Simulation results of these systems showed the possibilities of simulation applications and also provided useful outcomes that could be applied to vacuum system design in practice. The most commonly used vacuum systems in materials processing were selected as the modelling systems. Modelling was also based on the commercial specifications of vacuum systems used in experimental applications. Two different modelling with and without baffle effects on backstream were employed in this modelling with fixed design factors for the chamber, exhaust pipeworks. The simulation design factors of the modelled HV systems were fixed, with the same parameters being used except for the baffling applications in each simulation. Commercially available diffusion-mechanical (DP-MP) system was employed in this modelling. The proposed HV systems have a straight pipework with a length of 0.3 m and a diameter of 0.0254 m. The valves which were employed had internal aperture areas of $5X10^{-4}$ m^2 and $5X10^{-3}$ m^2 for rough and high vacuum pumping, respectively, and were normally opened in the absence of a signal. The chamber volume of the modelled HV systems was fixed at 0.3 m^3. The commercial specifications of the employed mechanical pump models are summarized in Table 1. The pump models were selected after repetitive simulations to obtain the optimum system modelling. The simulation schematic of modelled diffusion systems with and without baffles is illustrated in Fig. 1.

Table 1. Commercial specifications of employed rotary pump of diffusion system (Edwards Ltd.)

model name	E1M8
pumping speed (pneurop 6602, 50 Hz)	255 m^3/h
number of stages	2
ultimate vacuum without gas ballast	7.7×10^{-4} torr
Weight	225 kg
motor power	7.5 kW(10 hp)

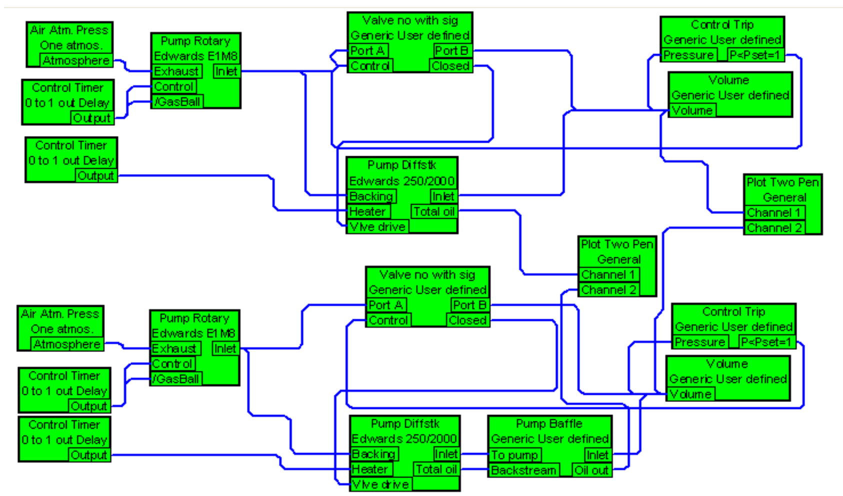

Fig. 1. Simulation schematic of diffusion system with baffle (bottom) and without baffle (top)

Both models with and without baffle were simulated to compare the effects of baffle applications on vacuum characteristics of system. Achieved in situ vacuum characteristics are plotted in the form of the pump-down and backstream curves in Fig. 2, 3. The dynamic characteristic curves with and without the baffle effects are indicated by the dotted and solid lines, respectively. The simulation results showed that the baffle effects are significant to the overall performance of system. The ultimate pressure of the DP system with baffle was reached almost at 10^{-7} torr (Fig. 2) which was approximately same as the without baffle model. Effects of baffle employment were not observed within the initial evacuation time of 32 minutes. In addition, the pumping down curve with baffle system was gradually stabilized compared to the abrupt behavior of without baffle. The employment of a baffle had a greater effect on the evacuation time and on the degree of backstream than on the ultimate pressure. The initial baffle effects of both DP systems were reflected in their pumping times to the ultimate pressure of about 43 minutes without a baffle and 26 minutes with a baffle. Concerning the process time, the decrease of almost half order was obtained by the employment of baffle. Figure 3 represented the differences on backstream behavior of DP system which was expected. Achieved simulation results of baffle effects on vacuum characteristics suggested the feasibility of VacSim$^{(multi)}$ applications for this study. In-situ simulation data plotted as vacuum characteristic curves in Fig 2, 3 were summarized on table 2.

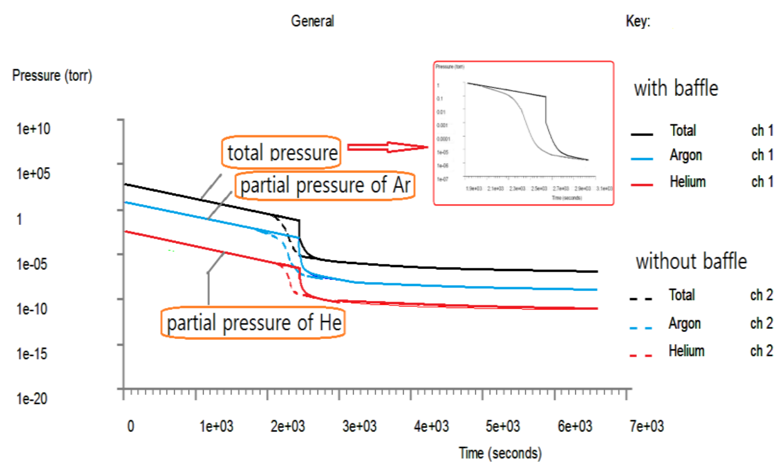

Fig. 2. Comparison of pumping down curve with and without baffle employment of DP system

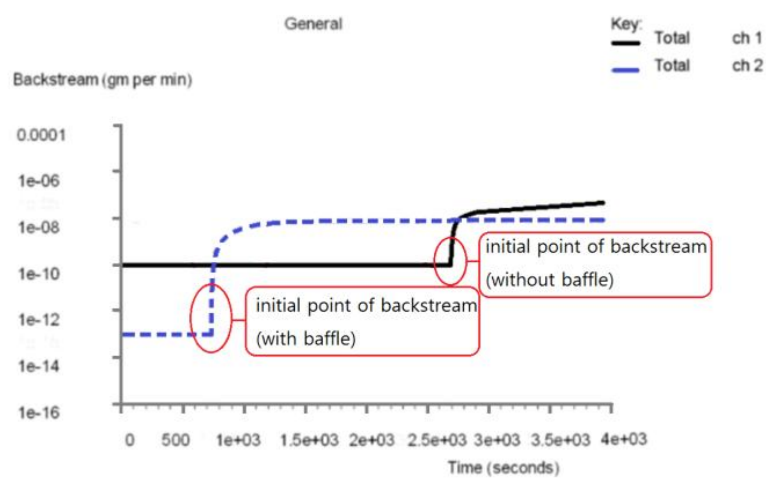

Fig. 3. Comparison of backstream with and without baffle employment of DP system

Table 2. In-situ simulation data on characteristic curves of DP system

Modelling of DP system	Ultimate pressure (torr)	Pumping time (sec)	Maximum backstream (gm/min)
Without Baffle	$6X10^{-7}$	3003	$5.29 X 10^{-8}$
With Baffle	$2X10^{-7}$	2695	$8.03 X 10^{-9}$

2.2. Simulation of throttle valve system

VacSim$^{(multi)}$ provide the two different modelling components, pressure limit valve and controlled valve, for the simulation of variance conductance throttle valve system. The valve components were modelled as circular apertures the size of which is reduced to zero when closed. Turbomolecular HV system which is commonly utilized on material processing was employed for this simulation. Commercially available model of turbomolecular-mechanical pump (TMP) was chosen as the simulation model. Modelling of the throttle valve by controlled valves was consisted of the control trip and normally open/close valve with signals modules. The control trip component behave like pressure-sensor which send control signal “1” if the chamber pressure is lower than the preset pressure. Control signal “1” is fed to the normally open valve which is open when the controlled signal is less than 0.5. Purpose of throttle valve employment is to sustain the chamber pressure constantly, reliably during the process. The preset pressure was set to 10^{-3} torr as the constant process-pressure. Therefore, the modelling of controlled valve provided variable conductance characteristics by closing the normally open valve unless the chamber pressure is higher than 10^{-3} torr . To sustain the variable conductance accurately, the controlled valves are fully open and close according to the pressure of chamber. If the chamber pressure fall down to below 10^{-3} torr, the control valve is closed to keep chamber pressure constant. The closed indicator is 1 when the valve is closed. Simulation scheme of the controlled valve was represented in Fig. 4

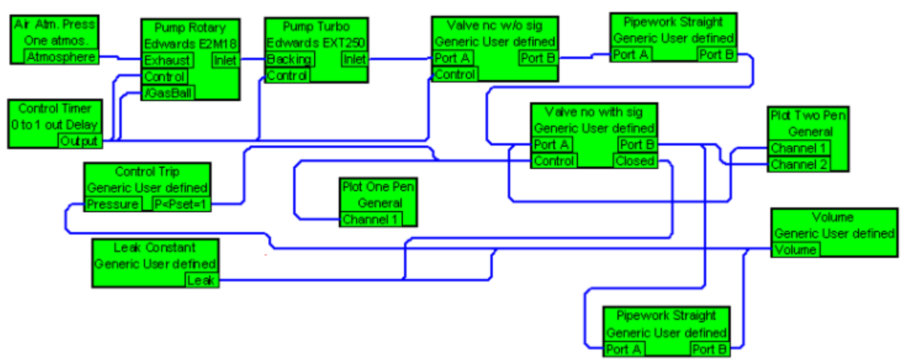

Fig. 4. Simulation schematic of throttle valve system with controlled valve

The pressure limit valve opens whenever the preset pressure difference between the high and low pressure port is greater than the constant process-pressure of 10^{-3} torr. The amount the valve opens is proportional to the sensing pressure difference during simulation. High and low pressure of pressure limit component represented the in-situ pressures at chamber and at exhaust pipe toward TMP respectively. The pressure limit valve doesn't have a control input, but have analogue signaling output (0=closed, 1=open). Figure 5 showed the simulation scheme of variable conductance system by pressure limit valve. Reflect the temperature increase during film deposition process, outgassing effect at fixed process temperature of 170 C was also considered on modelling.

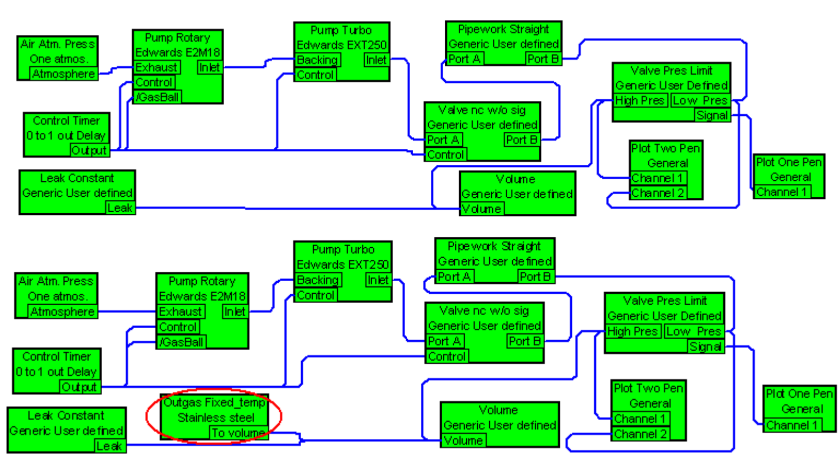

Fig. 5. Simulation schematic of pressure limit valve system without outgassing effect (top) and with outgassing effect (bottom)

3. Results and Conclusion

Feasibility of employed simulator, VacSim(multi),was verified with the simulation of commercial model of DP high vacuum system. Simulation of controlled valve system showed that the elapsed time of 1147 sec to be reached the valve closed was agree with the pumping down characteristics of chamber (Fig. 6). After the elapsed time of 1147 sec, constant chamber pressure of approximately 10^{-3} torr was sustained as the dotted line on pump-down curve. As the solid line on the curve, the pressure at port A of normally open control valve which indicate the point near to TMP was reached to ultimate pressure of 10^{-11} torr. Characteristics of variable conductance for the constant chamber pressure was obtained by the simulation of controlled valve modelling. As shown on Fig. 6 there was no partial open/close state on the operation of control valve. During the duration, approximately 1653 sec, of constant chamber pressure, the virtual leakage was estimated to be negligible. Suggested modelling of controlled valve showed the possibility of simulation for variable conductance system. In addition, the achieved simulation results were consistent with the observed pumping behavior of throttle valve experimentally.

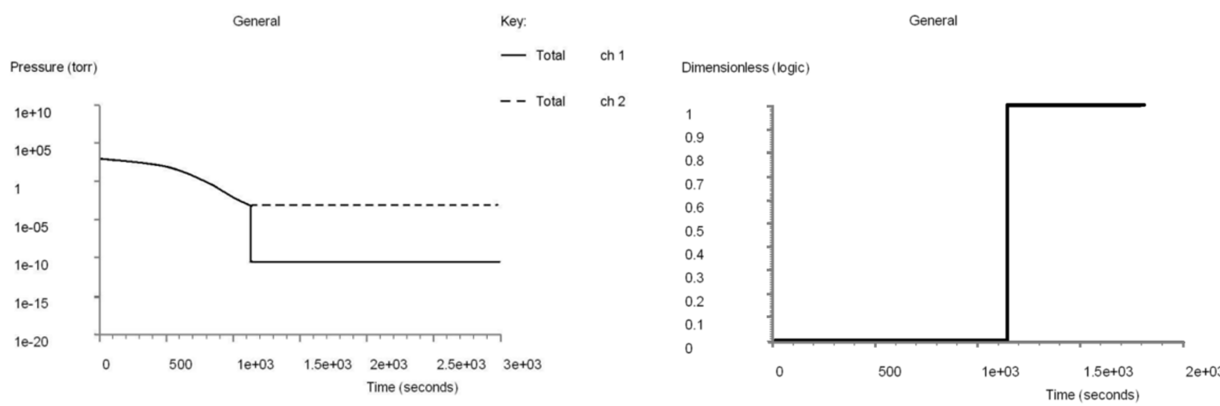

Fig. 6. Pump-down curve (left) and valve on/off state of controlled valve system (right)

Simulation results of the pressure limit valve was plotted on Fig. 7, 8. Comparison of outgassing effects to the variable conductance characteristics was represented on each plot. Pumping curve showed the in-situ variation of pressure at chamber and at exhaust line as the solid and dotted lines respectively (Fig 7). Chamber pressures were stabilized constant to 10^{-3} torr at the around 965 sec on both model. It was analyzed that the maximum conductance of pressure limit valve was at around 965 sec which also observed on Fig. 8. It was indicated that the values on both initial point of stabilized chamber pressure and of maximum conductance of valve was agreed with each other. As expected, the more gradual behavior of pumping down was observed with outgassing model. The state of valve opens as the degree of variable conductance was plotted in Fig. 8. The maximum degree of valve open was almost same as 0.08 on both model. It was fairly smaller than the expected value. In addition the pumping time of maximum valve open was also close at 963 sec and 968 sec on both model. Relatively large differences of pumping duration was noticed to reach the state of valve close. It took almost twice longer pumping time (830 sec) on the outgassing model. Achieved in-situ simulation data was summarized on Table 3.

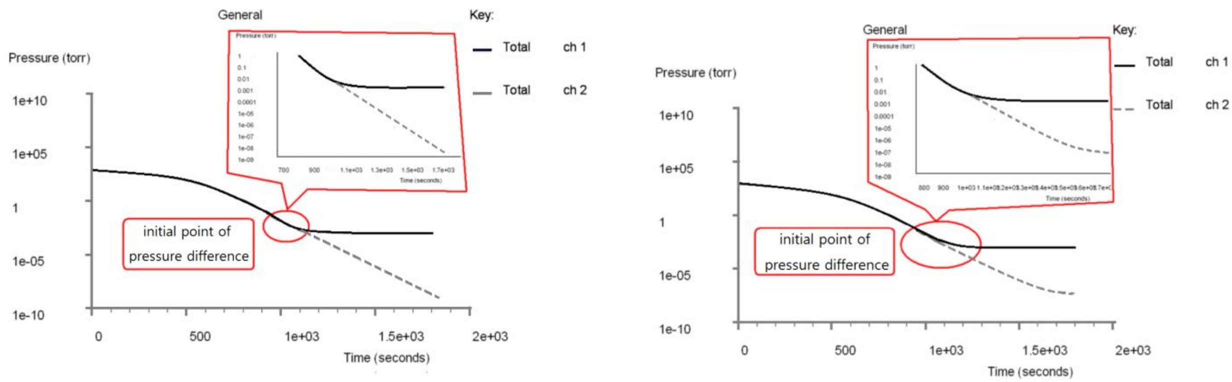

Fig. 7. Simulation results of pumping down characteristics of pressure limit valve system without outgassing effect (left) and with outgassing effect (right)

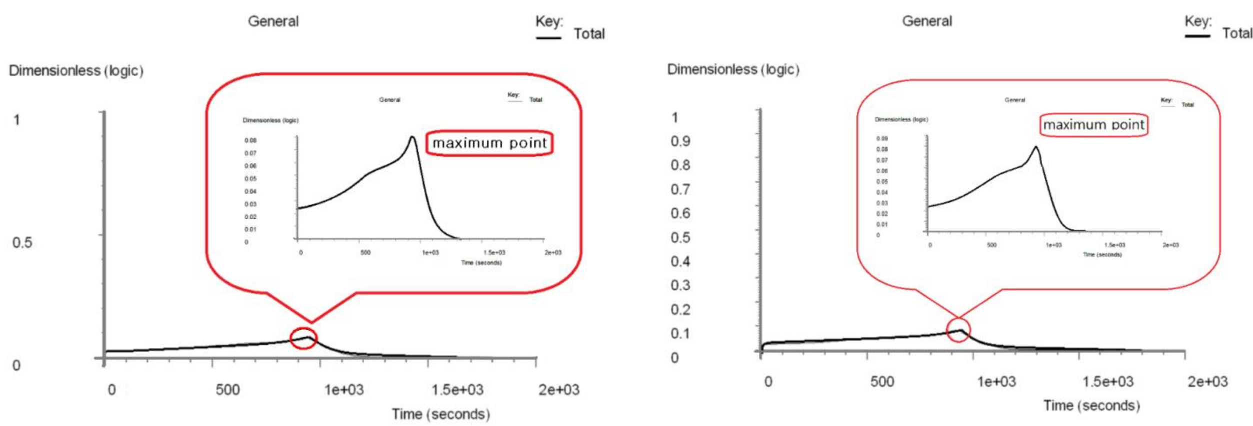

Fig. 8. Simulation results of on/off state of pressure limit valve without outgassing effect (left) and with outgassing effect (right)

Table 3. In-situ simulation data on the degree of variance conductance of throttle valve

Modelling of throttle valve system	Maximum conductance of pressure limit valve (dimensionless)	Pumping time to maximum conductance (sec)	Ultimate pressure @ pumping time of 30 min. (torr)
Without outgassing	0.07	939	5.97^{-9}
With outgassing	0.08	931	8.2^{-8}

Simulation of pressure limit valve also confirmed the feasibility of simulation modeling in design of variable conductance applications. To simulate the overall performance of vacuum systems, it is necessary to consider the tolerance of all of the design factors. However, the present preliminary study enabled us to evaluate the feasibility of using simulation for studying vacuum systems in a reliable manner.

Acknowledgment

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