Abstract #1862, 224th ECS Meeting, © 2013 The Electrochemical Society

Diaphragm Durability Enhancement for Valves Supplying Gas for Atomic Layer Deposition

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I. Introduction

The electronics industry made staggering progress in the latter half of the 20th century as seen by the major advancements that have been achieved with information technology devices such as personal computers, cell-phones and LCDs. What determines the performance of these electrical products is the semiconductor integrated circuitry, which is essentially made of silicon. The CVD, etching and other processes for manufacturing semiconductors from silicon use a multitude of gases. In these processes, gas is supplied directly to the wafers in a chamber to deposit films and etch to form extremely fine patterns. Therefore the valves used in these processes developed specifications for semiconductor manufacture, and not found in conventional industrial valves, i.e., external leak-free, particle-free and dead space-free. The standards that guide these specifications continue to become stringent alongside the increasing degree of integration of semiconductors, with direct diaphragm valves being the mainstream today. Recent advances in semiconductor processing include high dielectric constant (High-k) films used as gate insulators to increase the grade of integration and speed of LSI, while lowering power consumption. To form the film, Atomic Layer Deposition (ALD) has been adopted because it excels in step coverage and can control film thickness on the nanometer order. In ALD, the gas supply to and exhaust from the process chamber repeatedly at high speed. One process is 1 sec or less and valve operation is performed accordingly, and the valve operation exceed 1 million cycles per year. Therefore, high durability, e.g. more than 10 million cycles is demanded of process valves. However, 4 million cycles is boundary of cycle life of conventional direct diaphragm valves, because it has never been sufficient discussion about analysis of stress on diaphragm.

In this regard, durability of a direct diaphragm valve was estimated by stress analysis of its plate-like diaphragm and plotting those results on an S-N curve. The valves were built based on the simulation result with a goal of increased the durability performance.

II. Experimental

The relationship between fatigue strength of metals and the number of open/close cycles can be obtained from an S-N curve. Therefore, numerical analyses were performed and compared those findings to experimental results to examine the impact that valve lift has on diaphragm durability. The cycle life of the diaphragm was estimated by using the S-N curve of the diaphragm material and the result of stress analysis based on the simulation result.

Secondly, in order to validate the simulation, direct diaphragm valves were built and durability cycle test was performed at room temperature (23 +/-1 degree C), 1 MPaG pressurized and the cycle frequency of one cycle in every 2 sec.

III. Results and Discussions

The stress on diaphragm of the direct diaphragm valve is important parameter to estimate the cycle life of the diaphragm. We performed the stress analysis by finite element method for 26 mm dia. diaphragm with 1.20 mm valve lift condition. The average stress and the stress at the maximum amplitude were obtained from stress condition occurred in the diaphragm. Finally the maximum stress from the formula of modified Goodman. From this analysis, it was found that the stress applied to the diaphragm increases with displacement of valve lift and the maximum stress was 952.9 MPa at a maximum valve lift of 1.20 mm.

The fatigue limit stress of diaphragm of Ni-Co alloy that diaphragm material can estimate from S-N curve of this alloy, and it is found that the fatigue limit of diaphragm of Ni-Co alloy is 760 MPa. This value indicates the cycle life of diaphragm is infinite, if the stress on diaphragm is below 760 MPa. The obtained stresses from the simulation are applied to the S-N curve, and cycle life of the diaphragm and number of cycles to the diaphragm breaks was estimated. Figure 1 shows the cycle life of diaphragm from this estimate and the result of experimental valve cycle test performed under same conditions as the stress analysis, by using the direct diaphragm valve with predetermined valve lift. In this figure, the point of the maximum valve lift of 1.2 mm indicates that stress on diaphragm is 952.9 MPa. And the cycle life for that point is able to estimate from S-N plot as 1.5 million cycles. In the same manner, the cycle life is estimated 2.5, 4 and 6 million cycles at the valve lift 1.08, 0.96 and 0.84 mm, respectively. The maximum stress applied to the diaphragm decreased as the valve lift decreased and as a result, the cycle life increased. The fatigue limit stress at which the cycle life exceeds10 million cycles is 760 MPa per S-N curve and according to the result of stress analysis, the valve lift at that point is 0.78mm. On the other hand, experimental valve cycle test was performed under same conditions as the stress analysis, by using the direct diaphragm valve with predetermined valve lift. The diaphragm break occurred at 1.5million for 1.20mm valve lift and 2.5 million cycles for 1.00mm valve lift. However the diaphragm break had not occurred at 150 million cycles while the cycle test was still going on for 0.80 and 0.75mm valve lift. This experimental test result matches with the estimated cycle life curve. The findings described above prove that the diaphragm durability can be estimated by applying the stress analysis results for a given diaphragm to an S-N curve. It made clear that the higher durability of diaphragm is realized by optimum valve lift design and failure risk of equipment due to valve can be decreased.

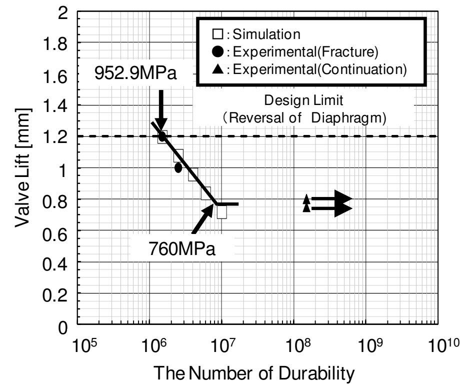

Figure 1 Estimated durability (number of cycles until diaphragm breaks) by valve lift.