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Simple Ion Beam Solutions

IBAD Coatings: Rate Sensitivity for SiO_2

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This investigation examined the how the deposition rate of SiO_2 is effected by a select few ion beam process parameters. The key parameters studied were beam current, accelerator voltage, gas flow to the sputter target and background pressure. Deposition rates were monitored using two quartz crystal microbalance (QCM) sensors. In addition, several single layers of SiO_2 were deposited onto Si substrates for thickness measurements. The results are presented in this paper.

Introduction

Ion beam sputter deposition with an assist ion beam has been used in industry for years to produce dielectric coatings used for optical devices [1-3]. An ion beam assisted deposition (IBAD) system utilizes two sources as depicted in Figure 1. One ion beam source (deposition source) is directed at a target material to be sputtered. The system geometry is designed so the sputtered target material arrives at the substrates while ions from the second source (assist source) are also arriving.

For designs of thin film optical filters that require multiple layers, an IBAD system may take several hours to deposit the desired structure onto the substrate. The coating time can approach 40+ hours depending upon the type of thin film design. It is therefore essential the system maintain a stable deposition rate for the coating duration.

Deposition rate for an IBAD system is controlled by several parameters such as the ion source beam current and energy, assist source conditions, target angle and system geometry [4]. Most of these parameters remain constant (or fixed) for a coating process. Actual variation in deposition rate can be tracked using a quartz crystal microbalance (QCM). Witness pieces provide a total result of the process. The purpose of this study is to examine a few parameters and rank them according to their degree of influence.

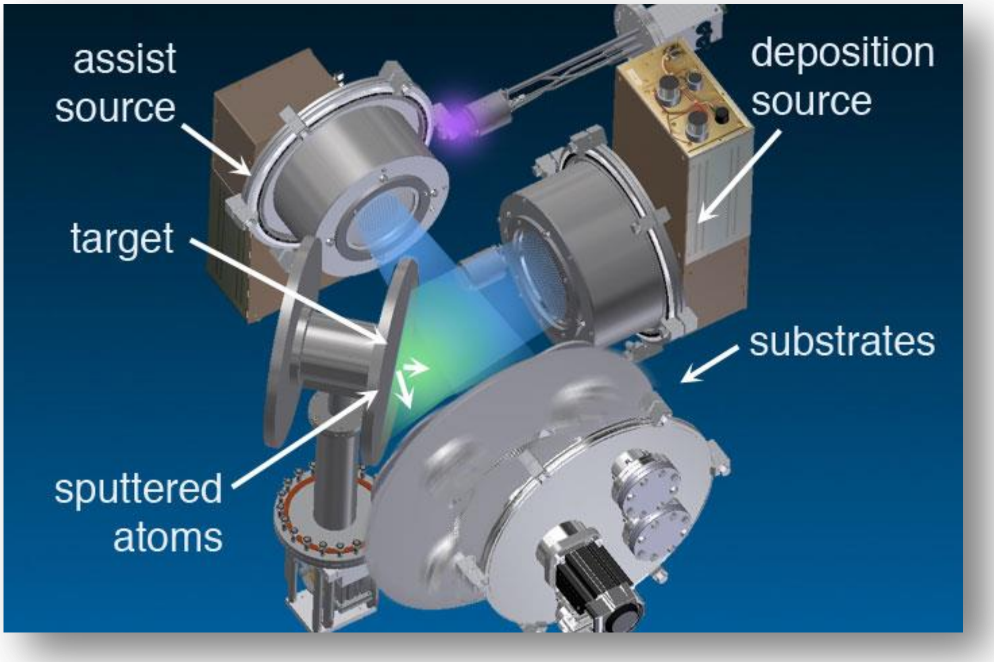

Figure 1. Dual ion beam sputter system layout.

Experimental Apparatus and Procedure

Single layers of SiO_2 reactively sputtered from a Si target were deposited onto Si wafers in the Techne dual ion beam sputter system. The 16 cm radio frequency (RF) deposition source was operated on Argon and the beam conditions were optimized to match industry standards (e.g. for these tests 400 mA beam current and 1250 V beam voltage). Oxygen was supplied to the target and the partial pressure was optimized for coating stoichiometry. The Si wafer witness pieces were mounted to the planetary fixture and rotated near 0.3 rps. For simplification purposes, the assist source was not used for this study.

For each test, the Techne system was baked at 100°C and pumped to 3×10^{-6} Torr for water vapor removal. The deposition source was warmed up for 10 minutes and the Si target was sputter cleaned for 10 minutes. An Inficon SQC-310 deposition controller monitored 2 quartz crystal microbalances fitted with an alloy type crystal. Both crystals were located near top dead center of the planetary fixture as depicted in Figure 2 and were cooled using a Lytron chiller. The crystal tooling factors were set to a default of 100%. Rate and thickness data were also captured every second on the Techne controller.

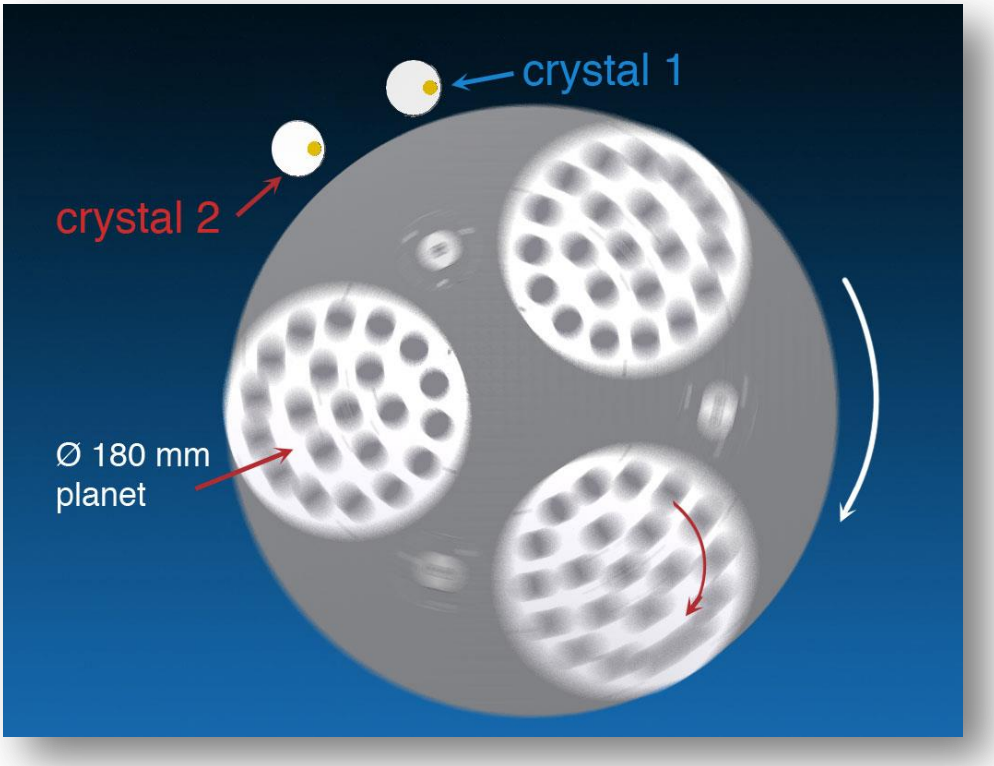

Figure 2. QCM location near planetary fixture.

The coated Si wafers were analyzed using a Semiconsoft MProbe spectrophotometer. An optical reflection measurement from 400 to 950 nm was obtained and a curve fit applied to estimate a physical thickness for each sample. Deposition rates were calculated by dividing the calculated physical thickness by the 1800 seconds of coating time per run.

Results and Discussion

First, to obtain accuracy brackets, several baseline runs were performed. The baseline conditions for the parameters investigated were: 400 mA beam current, 250 V accelerator voltage, 22 sccm target Oxygen and 7.3×10^{-4} Torr background pressure. Details for the average rate, measurement accuracy and crystal life are presented in Table 1. These data indicate a larger error with a crystal that has been coated for several hours (lower life).

Crystal	Average rate [Å/s]	Error [%]	Life [%]
1	0.82	±0.6	95
2	0.77	±1.5	61

Table 1. QCM baseline measurements

Next, the deposition source beam current was varied and QCM rate data were collected for each beam current condition. These data were then normalized by the average data in Table 1 with the results plotted in Figure 3. These data show strong rate sensitivity with changes to the beam current. A ±50 mA variation in beam current will produce a ±16 % rate variation as shown near 400 mA. At higher currents, the rate does not scale linearly as the film quality most likely departs from stoichiometric.

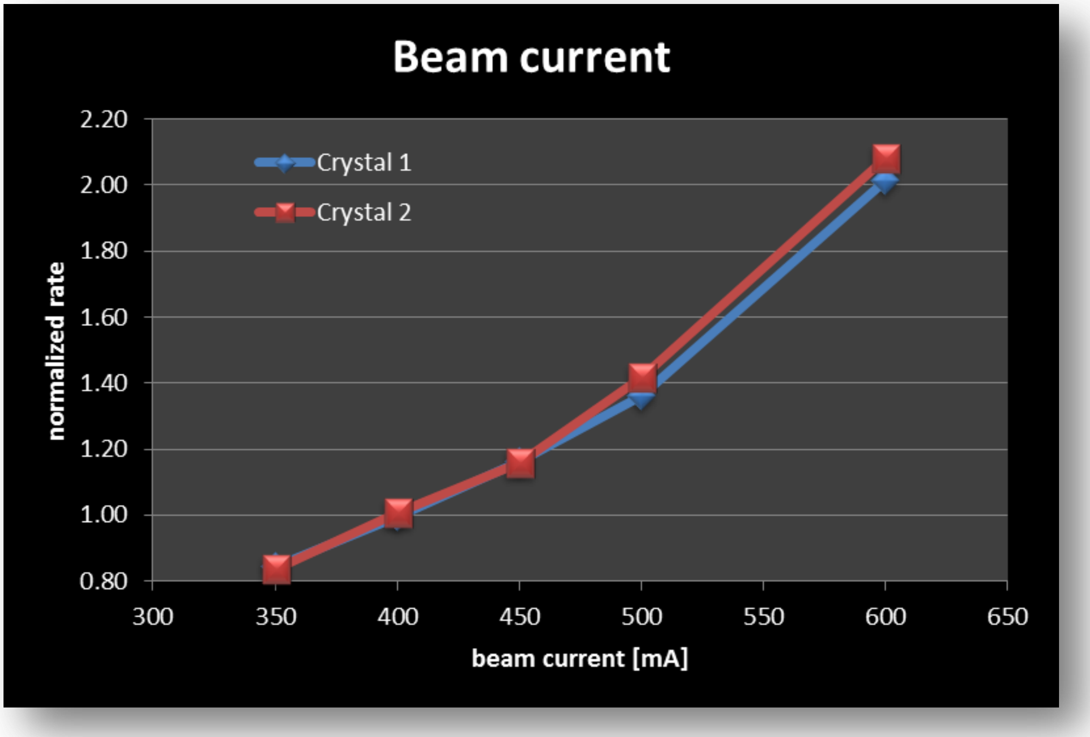

Figure 3. QCM rate with different beam currents.

Film stoichiometry is typically controlled with the target Oxygen flow rate. The data in Figure 4 show how the deposition rate varies with small changes to the target gas flow. The rate decreases almost linearly with increasing flow rates.

For comparison purposes, the remaining figures are plotted with the same Y-axis scale. Figure 5 shows how the rate varies when the accelerator voltage is adjusted. The accelerator voltage can be used to control the overall beam shape, though at lower voltages electron backstreaming may occur [4].

To simulate scattering collisions, the background pressure was increased by introducing additional Argon. Figure 6 shows a slight rate decrease with increasing background pressure.

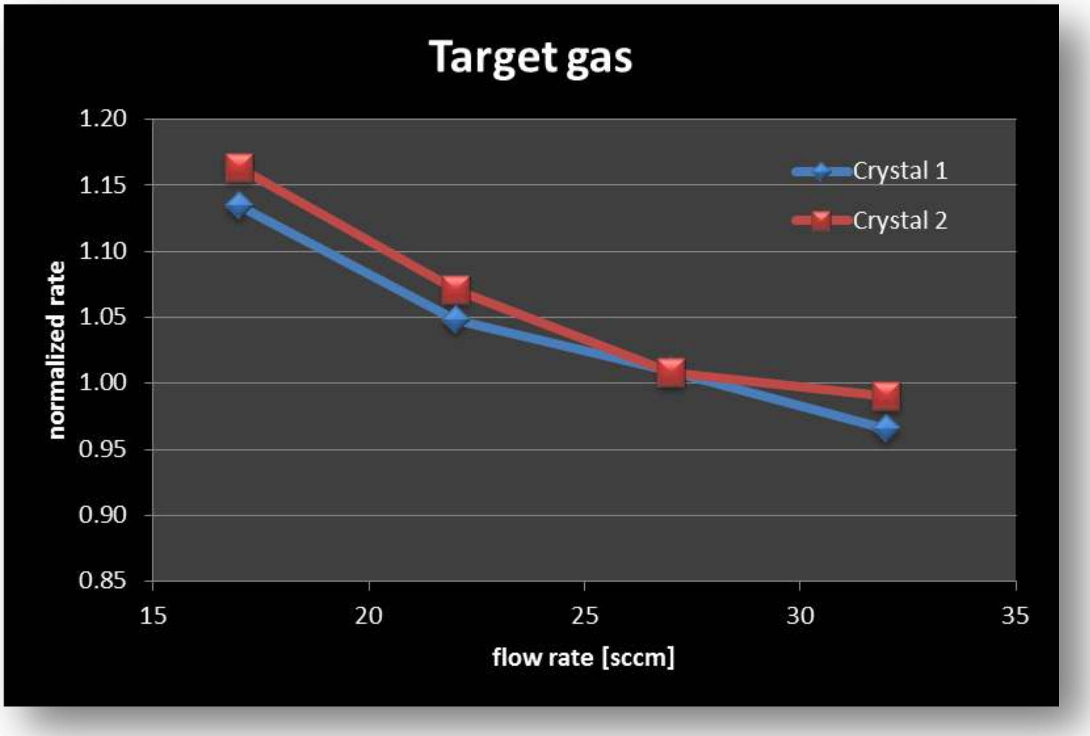

Figure 4. QCM rate with different Oxygen flow rates.

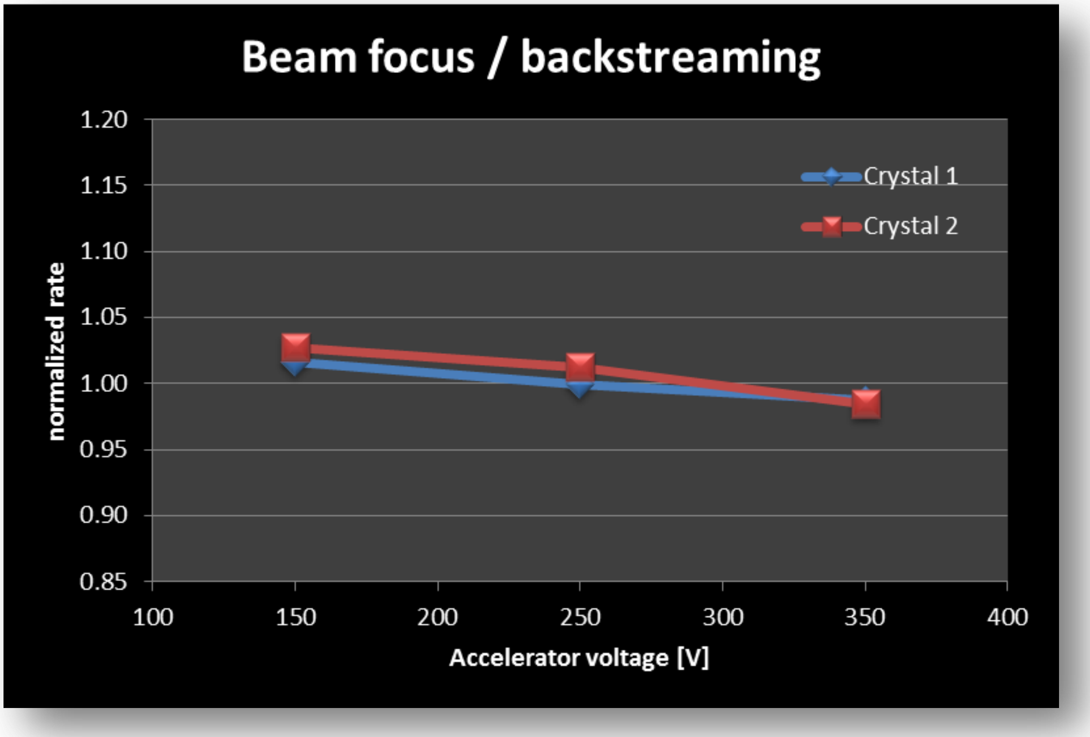

Figure 5. QCM rate at different accelerator voltages.

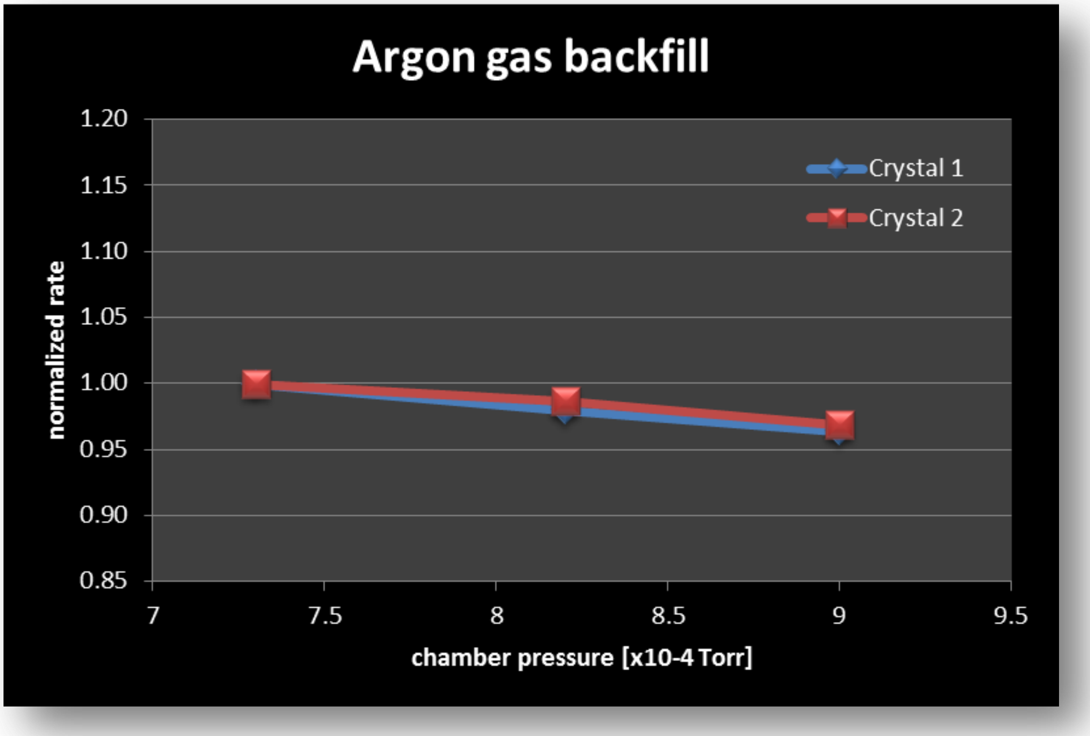

Figure 6. QCM rate at different chamber pressures.

It is clear from the data in Figures 3 through 6 that beam current and target Oxygen have the most influence on the deposition rate. Changes to the accelerator voltage and chamber pressure show a minimal influence on the deposition rate.

Correlation between the rate detected by the QCMs and rate measured at the planets was determined by coating single layers of SiO_2 onto Si wafer witness pieces. At the baseline condition, the average SiO_2 rate on the wafers was about 1.2 Å/s.

Rate changes with beam current and target gas were captured, normalized to the average rate and are plotted in Figures 7 and 8, respectively. For Figures 7 and 8, the physical rate on the Si witness pieces scale closely with the crystal data.

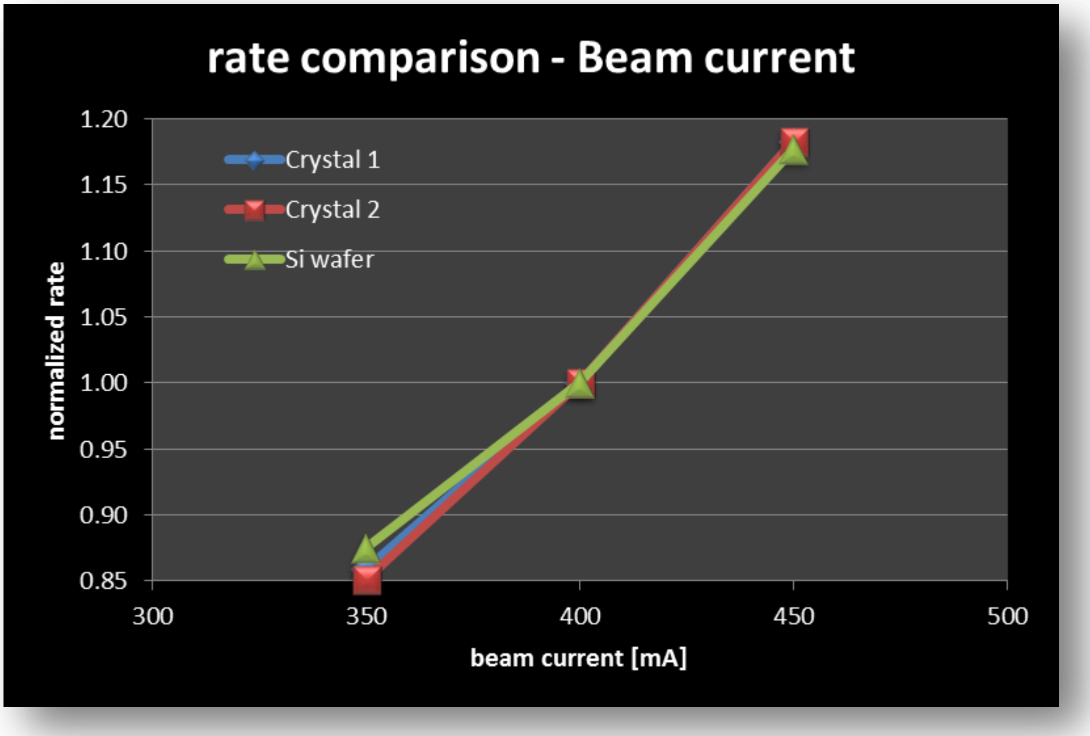

Figure 7. Comparison of rate data at different beam currents.

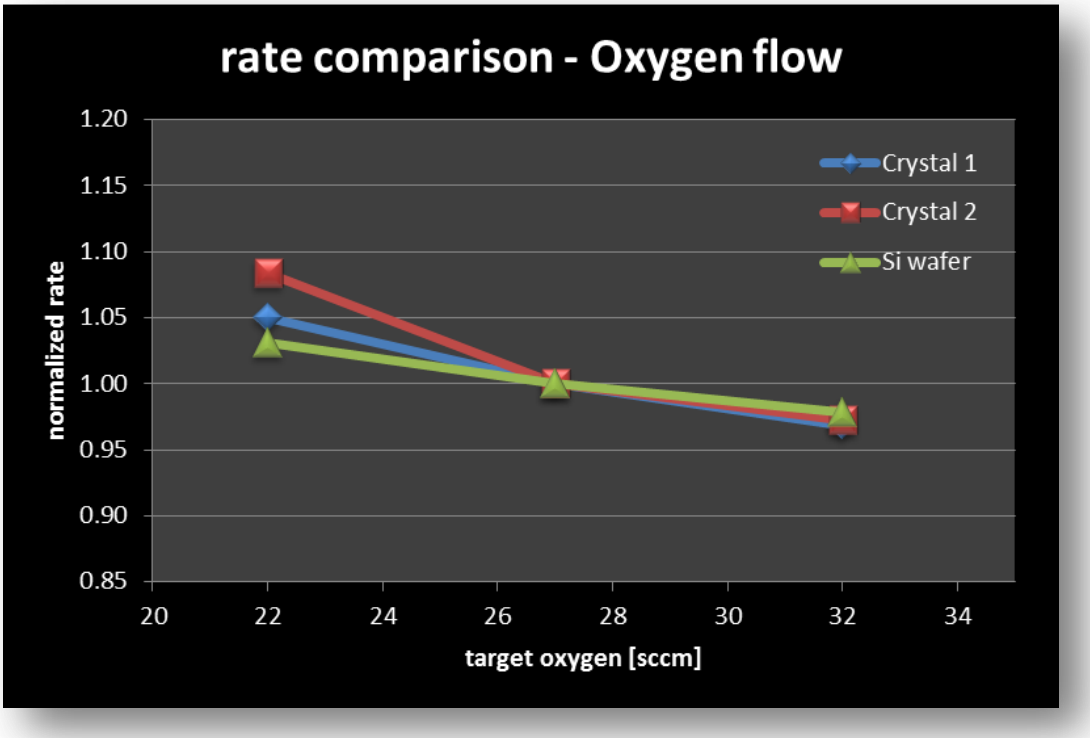

Figure 8. Comparison of rate data at different target gas flows.

Conclusions

The deposition rate sensitivity of SiO_2 reactively sputtered from a Si target was investigated. For the parameters investigated, the rate was very sensitive to the beam current and slightly sensitive to the target Oxygen. The rate did not appear to be as sensitive to the accelerator voltage and background pressure. Further studies are planned for different operating parameters.

References

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