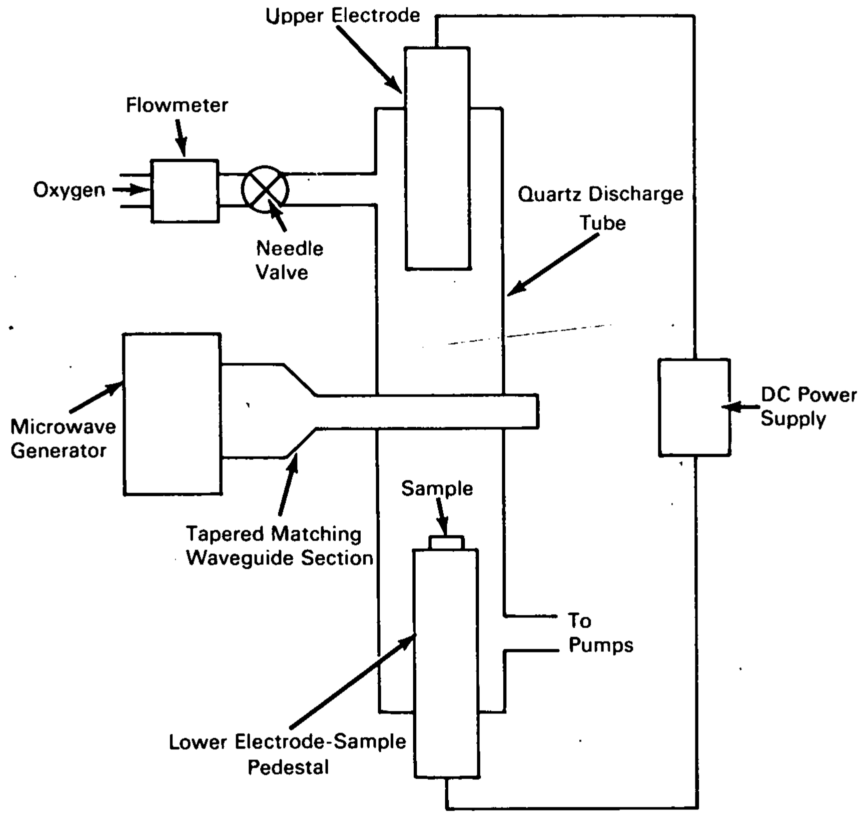
# NASA TECH BRIEF



## Silicon Oxide Films Grown in Microwave Discharge




Silicon dioxide films are used for a variety of purposes in the fabrication of silicon devices. Very high quality oxides are produced by thermal oxidation of silicon substrates. The flaw-seeking processes that occur during oxide growth probably assist in achieving this high quality. However, in order to produce films thicker than 1000 Å in reasonably short periods of time, the oxidation had to be performed at high temperatures (1100°C). The high temperatures involved in this process are undesirable for a number of reasons; e.g., redistribution of prior diffusion fronts may occur; dislocation densities tend to increase; and lifetime may suffer.

Electrical discharges have been used to produce oxide films at lower temperatures. Oxidation in a dc discharge does not appear to offer much promise of achieving the moderately thick films required in many device applications. Recently it has been shown that in the denser plasma produced in a microwave discharge, films thicker than 1000 Å can be produced rapidly.

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An investigation was therefore undertaken to characterize the growth behavior and the properties of the oxides obtained by this technique.

The results of the investigation show that the oxide growth can be characterized by a rate limiting diffusion process modified by sputtering effects produced by the discharge. The growth process provides a technique for rapidly oxidizing silicon at temperatures estimated to be 500°C or lower. At these low temperatures, growth rates corresponding to steam oxidization rates at 1100°C can be obtained. High quality oxides are produced by this process with properties which are for the most part indistinguishable from those of thermally grown oxides. MOS capacitance–voltage measurements indicate these oxides are essentially free of mobile ions.

The apparatus used to grow silicon oxide on a silicon substrate in a microwave discharge is shown in the figure. The quartz discharge tube had an 11-mm bore. A tapered matching waveguide section was used to couple power to the discharge tube from a 2.4-kMc/sec microwave generator with a power output variable between 500 and 1000 watts.

It has been previously shown that in dc discharges and microwave discharges the oxidation rate is enhanced if a positive dc potential is applied to the sample. Two electrodes were therefore inserted in the discharge tube for this purpose. The lower electrode acts both as the anode and the sample pedestal. The upper electrode in this system serves to complete the dc circuit; being cathodic it can also behave like a sputtering target. To prevent sputtered material from reaching the sample, the spacing between the electrodes was made large. At a pressure of 0.1 torr, the 20-cm spacing used between the two electrodes in this apparatus corresponds to a distance of about 200 mean free paths. Thus, material sputtered off the cathode should be scattered to the walls before reaching the sample.

The electrodes are a potential source of contamination. To minimize the problems from this source, silicon rods (9 mm in diameter) were used as the electrodes. Impurities driven from the walls of the discharge tube (resulting from bombardment of the walls by energetic species in the discharge) serve as another potential source of contamination. To minimize contamination from this source the apparatus was operated as a dynamic flow system, with oxygen being metered into the system through a needle valve.

In the dynamic system both the flow rate and pressure influence the discharge characteristics. Pressure measurements in this system were made at the outlet end of the discharge tube. Under conditions of constant outlet pressure, the pressure in the main body of the discharge tube increases with flow rate. The pressure in the main body of the discharge tube can be estimated from the appearance of the discharge. Under conditions of constant flow rate, outlet pressure, and microwave input power, the reproducibility achieved in overall system performance was the same under dynamic and static conditions.

In a typical experiment, a 6 × 6 mm square silicon wafer was placed on the sample pedestal and the system evacuated to the $10^{-6}$ to $10^{-7}$ torr range. Oxygen was metered into the system at 50 cc/min and the outlet pressure adjusted to 0.15 torr. With the microwave generator adjusted to deliver about 600 watts, the electrodeless microwave discharge produced a pale red oxygen plasma in the discharge tube. Under these conditions the volume of the plasma was sufficient to immerse the ends of both silicon rods (and the sample) in the plasma. The regions surrounding the ends of the silicon rods were characterized by an intense white glow. Oxide growth was observed on the sample and on both silicon rods.

At higher pressures the plasma became a deeper red; at lower pressures it gradually changed over to a bluish-white. At pressures below about 0.01 torr it was impossible to maintain a discharge in the tube. The volume occupied by the discharge increased as the pressure was reduced.

With other conditions constant, increasing the microwave input power increased the volume occupied by the discharge without significantly changing the appearance of the discharge. This result suggested that variation in the microwave power input did not produce significant changes in the plasma density, but only in its total volume.

The most significant effects produced by changes in the flow rate were ones that could be attributed to the accompanying changes in the pressure of the discharge. Sufficient experimental data is not available to predict the effects of flow rate under conditions in which the discharge pressure is held constant.

**Note:**

Inquiries concerning this investigation may be directed to:

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**Patent status:**

Inquiries about obtaining rights for the commercial use of this invention may be made to NASA, Code GP, Washington, D.C. 20546.

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