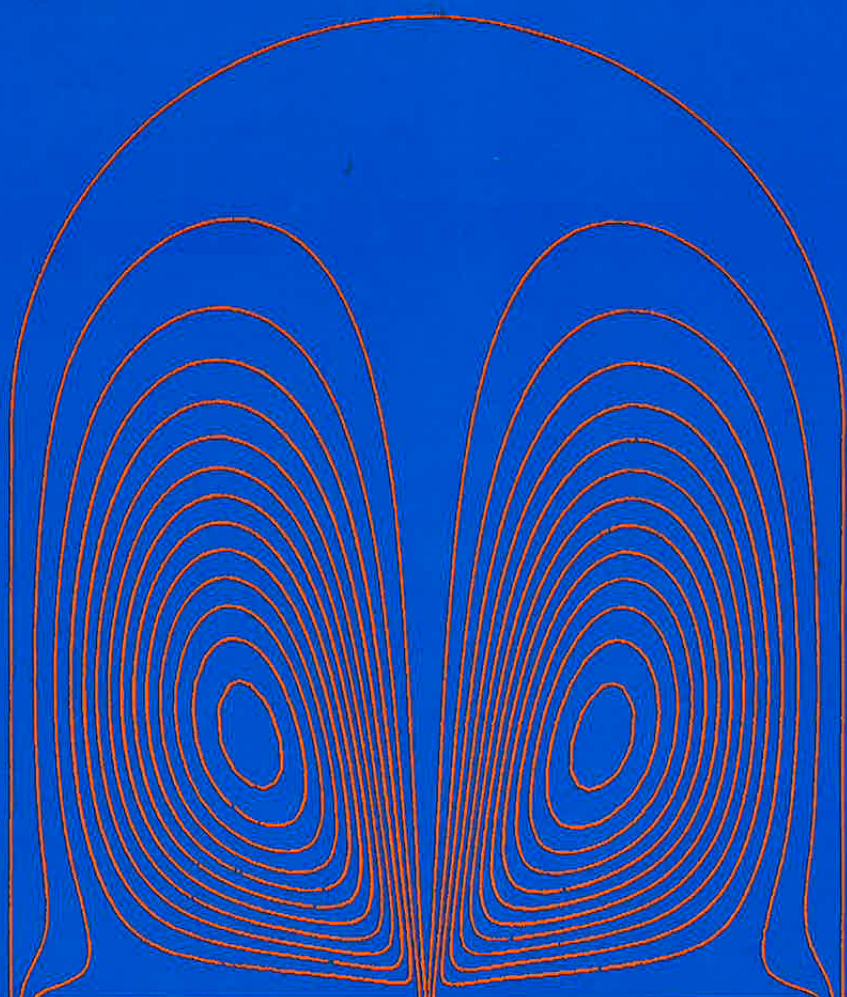
PROCESS ENGINEERING ANALYSIS IN SEMICONDUCTOR DEVICE FABRICATION



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CHAPTER 8

OXIDATION OF SILICON

8-1 INTRODUCTION

The controlled growth of a silicon dioxide (SiO_2) film on a silicon substrate is an essential and oft-repeated step in the fabrication of semiconductor devices. We begin this chapter with a brief description of the several roles played by silicon dioxide. This is followed by a review of the most common methods used to produce oxide films. Then we turn to an examination of models of oxide growth based upon different physical pictures of the thermodynamic, kinetic, transport, and mechanical events that accompany and affect the rate of oxide film growth.

One of the most common uses of silicon dioxide is as a *mask*, or barrier, against dopant diffusion into the semiconductor substrate. Through the methods of photolithography (Chap. 9) certain regions of an oxide film are protected against etching (Chap. 10). Then openings ("windows") subsequently etched in the oxide permit the entrance of dopants (Chap. 11) into the substrate. Unetched oxide retards the diffusion of dopant atoms. In this way dopants are segregated precisely into the desired regions of the substrate.

Because silicon dioxide is a good insulator it is used to provide electrical isolation between devices on a chip. In addition, a thin oxide film can form the dielectric layer of a capacitor. In this particular application, where the resistive character of the dielectric is essential, the chemical purity of the oxide film determines its effectiveness. In contrast, because a "mask oxide" is ultimately etched away, demands on its purity are somewhat less than those placed on the dielectric oxide film.

Silicon dioxide is a glass-like material. Hence it is resistive to intrusion of moisture and most ambient or environmental chemicals encountered in the neighborhood of electronic devices. For this reason an encapsulating film of silicon dioxide is often used to provide a protective covering over the completed device.

Finally, and of great importance, we note that oxidation of a crystalline silicon surface produces an important alteration of the electronic state of that interface. The surface of a bare silicon wafer represents a discontinuity in the perfection of the crystal lattice. The unsaturated covalent bonds of the surface atoms of the crystal (so-called dangling bonds) are essentially acceptor-like in their effect on charge transport at and near the surface. This gives rise to *surface states* that have a profound (and generally deleterious) effect on the electronic behavior of the semiconductor near its surface. Since devices are grown on (and just within) the surface, device function is altered by the presence of these surface states. The density of surface states can be reduced by four or five orders of magnitude simply by oxidation of a thin surface layer of the silicon. This reduction is often referred to as "electronic surface passivation."

The most common method of oxide growth is *thermal oxidation*. In the so-called dry method, silicon wafers are exposed to an oxygen atmosphere at 800–1200°C. The stoichiometry of the oxide growth is simply represented by

$$Si + O_2 \rightarrow SiO_2 \tag{8-1}$$

The chemical and physical events that control this reaction are discussed in more detail subsequently.

"Wet" oxidation is carried out by using water vapor (steam) as the reactive gas, with the reaction stoichiometry given by

$$Si + 2H_2O \rightarrow SiO_2 + 2H_2 \tag{8-2}$$

Wet oxidation is considerably faster than dry oxidation, but the properties of the two oxides are not identical.

Silicon oxide is also produced by chemical vapor deposition (CVD). In this method the silicon is supplied along with an oxygen-bearing compound, and the oxide is grown *on* the wafer rather than within the wafer, as in thermal oxidation. Various chemical systems have been used in oxide growth. Two examples are the dichlorosilane–nitrous oxide system

$$SiH_2Cl_2 + 2N_2O \rightarrow SiO_2 + 2HCl + 2N_2 \tag{8-3}$$

and the TEOS (tetraethylorthosilicate) system

$$Si(OC_2H_5)_4 \rightarrow SiO_2 + 2H_2O + 4C_2H_4 \tag{8-4}$$

Note that in the TEOS system the silicon *and* oxygen are borne by the same reactant.

8-2 DRY THERMAL OXIDATION OF SILICON

The classic model of thermal oxidation is due to Deal and Grove [R8-4]. The physical picture is suggested by Figure 8-1. As oxygen reacts at the original bare silicon surface a layer of oxide grows. Subsequent reaction requires that oxygen diffuse through the