[redacted] Oxidation

Silicon has the unique ability to be oxidized into silica, which produces a chemically stable, protective and insulating layer on the surface of the wafer. The production of high quality ICs requires an understanding of the basic mechanisms of oxidation [redacted] and the ability to form in a controlled and repeatable fashion a high quality oxide. The functions of the oxide layer are to:

(i) mask against diffusion or ion-implant;

(ii) passivate the surface electrically and chemically;

(iii) isolate one device from another; and

(iv) act as a component in MOS devices.

Thermal oxidation is the principal technique and is carried out between 900 and 1300°C in dry oxygen or steam with the following reaction occurring:

$$Si + O_2 \rightarrow SiO_2$$ [redacted]

$$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$ [redacted]

During oxidation, the Si–SiO_2 interface moves into silicon. Experiments have established that oxidation proceeds by the diffusion of the oxidizing species (oxygen ion, oxygen atom or molecule) through the oxide layer to the Si–SiO_2 interface. The volume increases during oxidation. The constraint to match the oxide layer with the underlying silicon introduces stresses, which put the oxide layer in compression. If the stresses in the oxide layer were tensile in nature, the brittle layer will crack and will be unsuitable. The interface constraint also generates dislocations and stacking faults inside the silicon near the interface.

For long oxidation times, the oxidation rate is parabolic, i.e., the oxide thickness increases as the square root of time. As a function of temperature, the oxidation rate follows the Arrhenius law (recall Sec. 2.4) with a linear plot of ln (oxidation rate) versus $1/T$. The activation energy for the process is found to be ~120 kJ mol^{-1} for dry oxidation and ~70 kJ mol^{-1} for wet (steam) oxidation.

If the silicon had been doped before oxidation, the dopant tends to redistribute itself in different concentrations in the two co-existing phases: Si and SiO_2. P, Ga, As and Sb dissolve more in Si than in silica; B behaves the opposite way. The segregation coefficient $k = c_{Si}/c_{SiO_2}$ is between 10 and 20 for P, Ga, As and Sb and less than one for B.

15.5.7 Doping

Impurity doping can be carried out by solid state diffusion under two conditions: (i) a constant surface concentration of the dopant is maintained at a high enough temperature so that the dopant diffuses in and creates a characteristic concentration profile; and (ii) a constant total quantity of the dopant is first deposited on the surface (predeposition) either by short-time annealing or by other techniques such as ion implantation at a low temperature. The concentration profile is then altered through a high temperature anneal in a non-doping atmosphere (drive-in).

A *p-n* junction is created by diffusing into the bulk semiconductor through a window in the oxide layer an impurity, say, a *p*-type, where the bulk crystal has already been doped to be the *n*-type. In practice, the concentration-distance profile of the dopant is approximated to two limiting cases: the abrupt junction profile. This is the case in a shallowly-diffused junction or ion-implanted junction. In the linearly-graded junction, the concentration profile is assumed to change linearly with distance.

When the impurity is diffused in through a window, it moves downwards as well as sideways. The final shape of the diffused region, instead of being a flat box, becomes a box with bulging sides and spherical corners. This shape has an important effect on the junction breakdown characteristics.

Avalanche multiplication is the most important mechanism of junction breakdown. The avalanche breakdown voltage imposes an upper limit on the reverse bias of diodes, the collector voltage of bipolar transistors and on the drain voltage of MOSFETs. If the electric field is high, the carriers may carry enough energy such that their collisions with atoms generate electron-hole pairs. The newly-created pairs in turn generate more pairs by collisions and the process multiplies like an avalanche, eventually causing breakdown. The avalanche breakdown voltage decreases with increasing impurity concentration. It is also less for cylindrical shape of the sides of the diffused region and when the corners are spherical.