OP-F: Drive In Furnace and Diffusion Processing

Filename: DRIVE

One of the most important process steps in silicon device fabrication is the formation of p-n junctions. Several techniques can be employed to form such junctions; the introduction of dopant impurities is usually done with ion implantation or diffusion. In our lab we use diffusion processing since it is considerably simpler than implantation. This process is particularly useful since we can use photolithography and oxide masking to produce intricate patterns of doped areas in the silicon wafers.

We use two different steps in our diffusion process: the predeposition (see OP-D, p. **Error! Bookmark not defined.**, and OP-E, p. **Error! Bookmark not defined.**) and the drive diffusion. Assuming the dopants move in one dimension only (i.e. normal to the wafer surface) the concentration vs. time in the wafer is governed by Fick's Second Law:

$$\frac{\partial N}{\partial t} = \frac{\partial}{\partial x}\left(N \frac{\partial N}{\partial x} \right)$$

where N is the concentration of diffusing atoms, D is the diffusivity, t is time, and x is the distance into the slice. In general, the diffusivity is a function of the concentration of diffusing atoms and of the temperature. However, if we assume that the impurity atom concentration is small relative to the silicon atom density and to the intrinsic carrier concentration at the diffusion temperature, and if we just consider diffusion at a particular temperature, then D can be taken to be a constant, and the preceding equation reduces to

$$\frac{\partial N}{\partial t} = N \frac{\partial^2 N}{\partial x^2}$$

This is often called the one dimensional diffusion equation, and D is termed the diffusion coefficient of the impurity material in the host material. Solutions of this partial differential equation that are applicable to the predep and drive diffusions are obtained by using appropriate initial and boundary conditions. In both cases it is convenient mathematically to assume that the host wafer is infinitely thick, with diffusion taking place from one side only. In practical terms this means that the profile of dopant remains shallow relative to the wafer thickness, typically a few μm relative to 600 μm.

Case I: Predep

In this case we assume there is an infinite supply at constant concentration of dopants at the surface of the silicon wafer (i.e. the BN or P wafers in our predep furnaces). The initial and boundary conditions are then:

$$N(x, 0) = 0 \quad ; \quad N(0, t) = N_o \quad ; \quad N(\infty, t) = 0$$

The solution to the diffusion equation under these conditions is a complementary error function:

$$N(x,t) = N_s \operatorname{erfc}\left(\frac{x}{2\sqrt{D\,t}}\right)$$

$$\operatorname{erfc}(y) = 1 - \frac{2}{\pi}\int_0^y \exp\left(-z^2\right)dz$$

The profile will look roughly like a decaying exponential. In our processing the predep is very short and D is fairly small (because the predep temperature is only 950°C), so we usually assume the predep profile is roughly a delta function at the surface. This will serve as an initial condition for our drive diffusion.

Case II: Drive-In Diffusion

In this case we assume there is only a limited supply of dopant atoms, initially located at the surface of the wafer, and that the total number of impurities in the sample (called the dose, Q_o) is a constant. The initial and boundary conditions are now

$$N(x, 0) = 0 \quad ; \quad \int_0^\infty N(x,t)dx = Q_0 \; N(0, t) = N_o ; \quad N(\infty, t) = 0$$

The drive diffusion serves to move the impurity atoms into the slice, while lowering the surface concentration. If we assume that all the impurities are initially located at the surface of the wafer (i.e., another initial condition $N(x, 0) = Q_o\,\delta(x)$), then the solution to the diffusion equation is a Gaussian,

$$N(x, t) = \frac{Q_o}{\sqrt{\pi D t}} \exp\left(-\left[\frac{x}{2\sqrt{Dt}}\right]^2\right) .$$

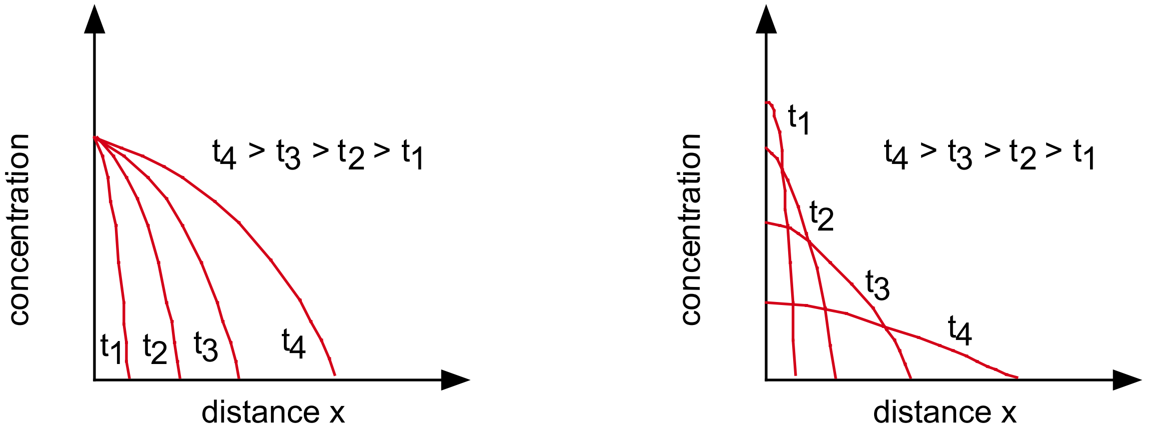
See Figure 1 for comparisons of the erfc and Gaussian curves.

We can see the substantial difference between the predep and drive diffusions by considering Figure 1. Figure 1a shows the constant source predep, and Figure 1b shows the limited source drive. For our furnace conditions, the scale on the x-axis in Figure 1a would be much smaller than on Figure 1b.

It is also possible to relate the sheet resistance, junction depth, impurity type, shape of diffusion profile, impurity surface concentration, and wafer background concentration. These curves are called Irvin curves, and are given on

References

- Ghandhi, Chapter 4.
- Sze, Chapter 5.



(a) Constant source diffusuion

(b) Limited source diffusion

Figure 1: Comparison of constant and limited source diffusion profiles.

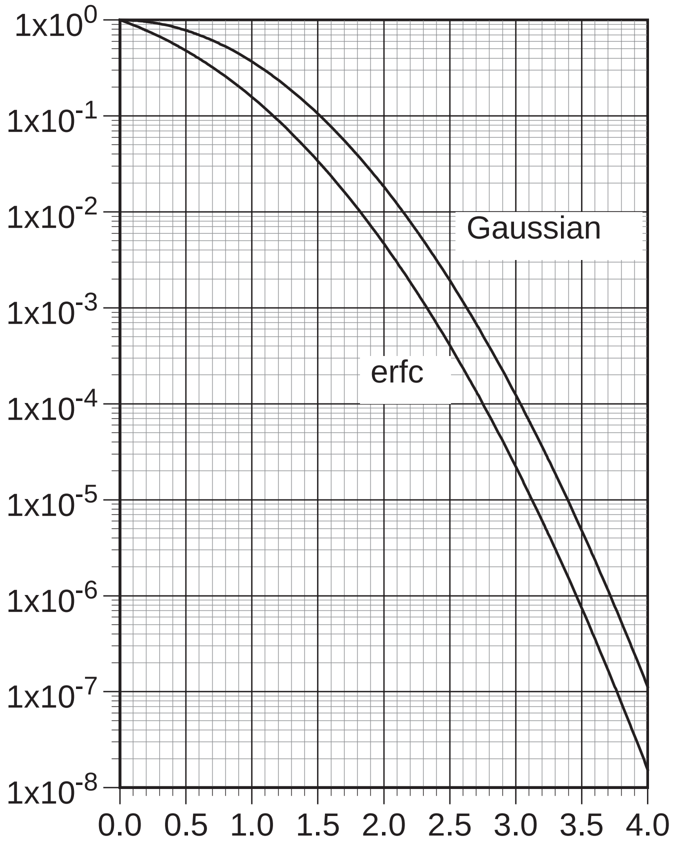


Figure 2: Normalized erfc and gaussian curves.

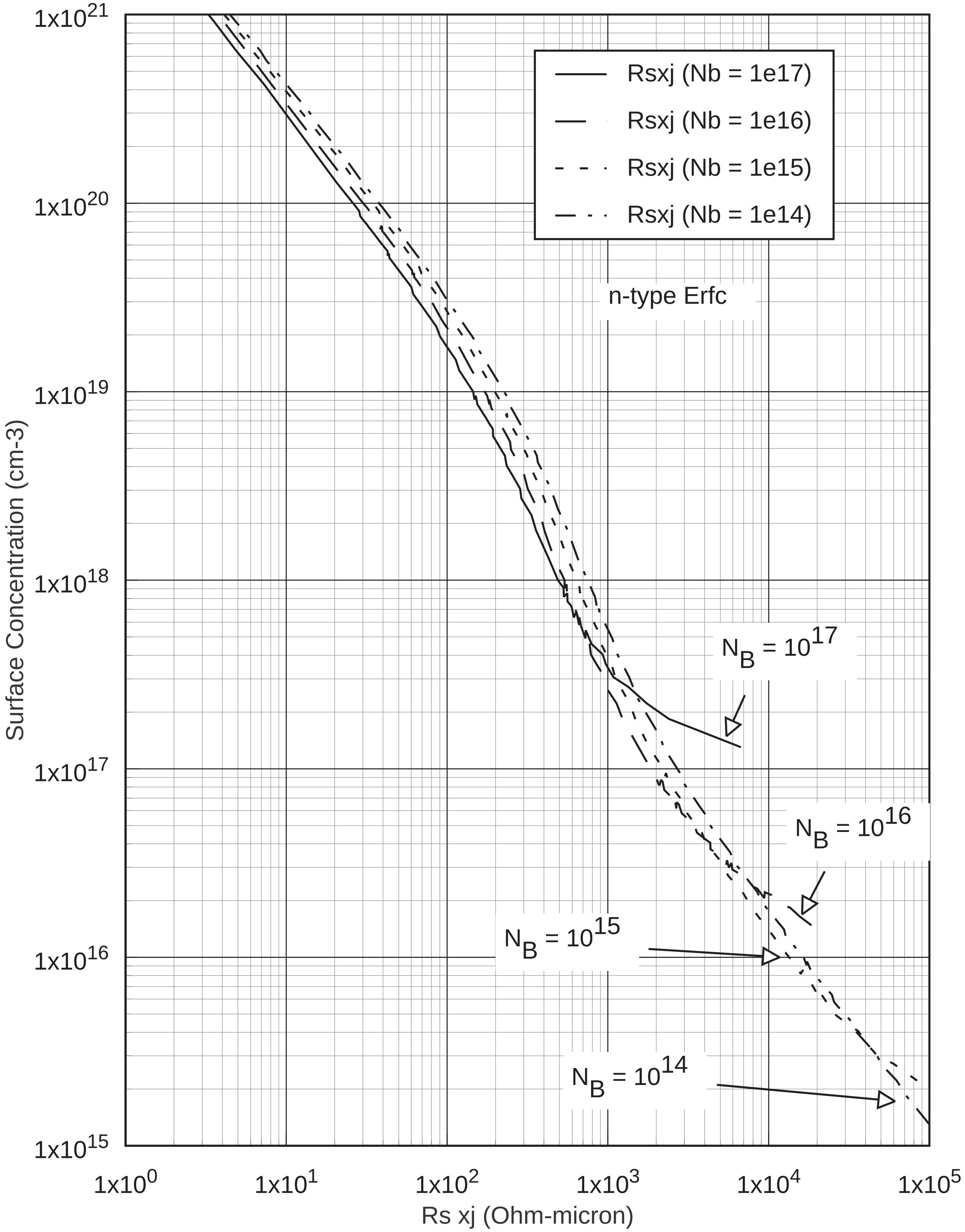


Figure 3: Irvin curve for n-type impurity, erfc profile.

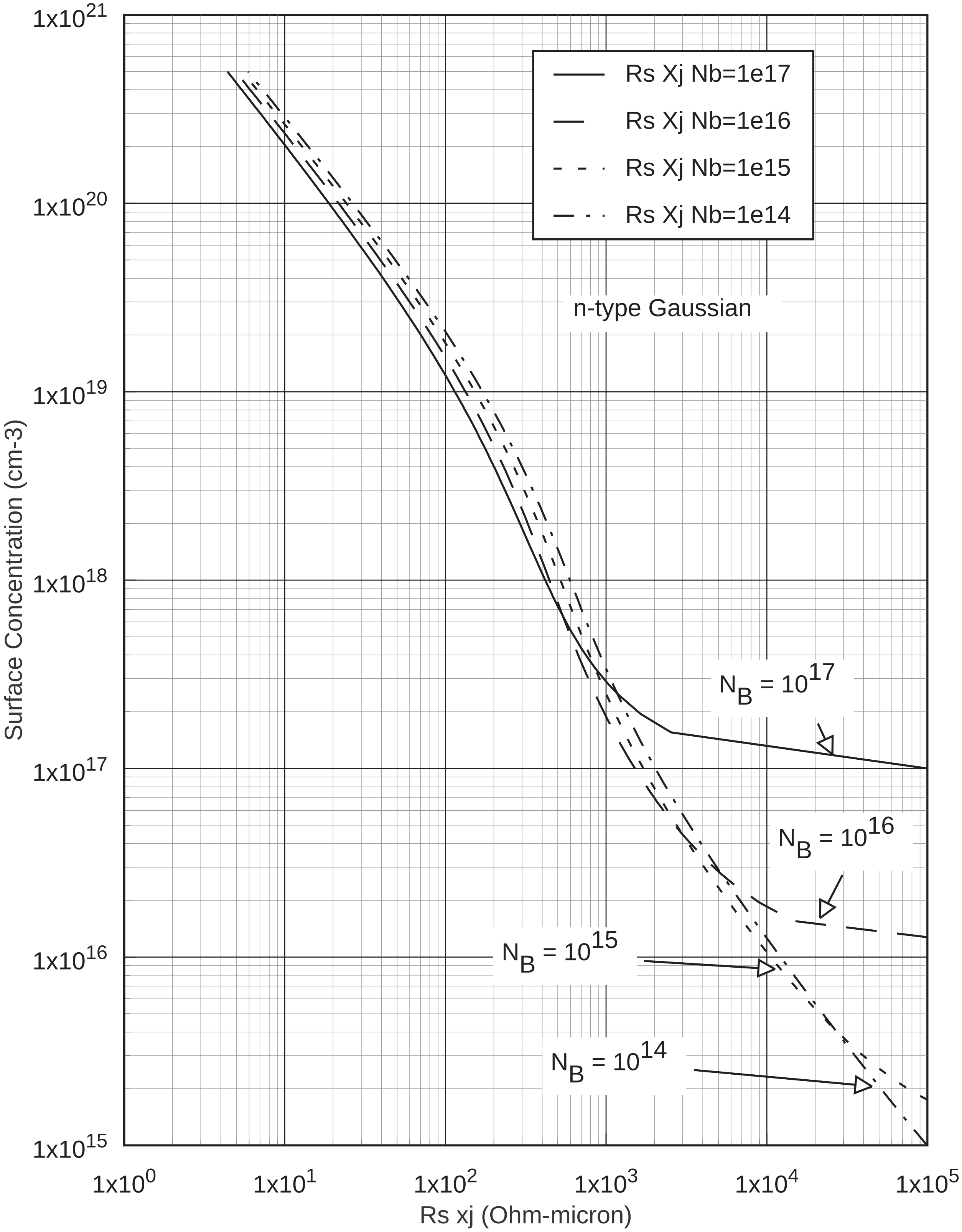


Figure 4: Irvin curve for n-type impurity, gaussian profile.

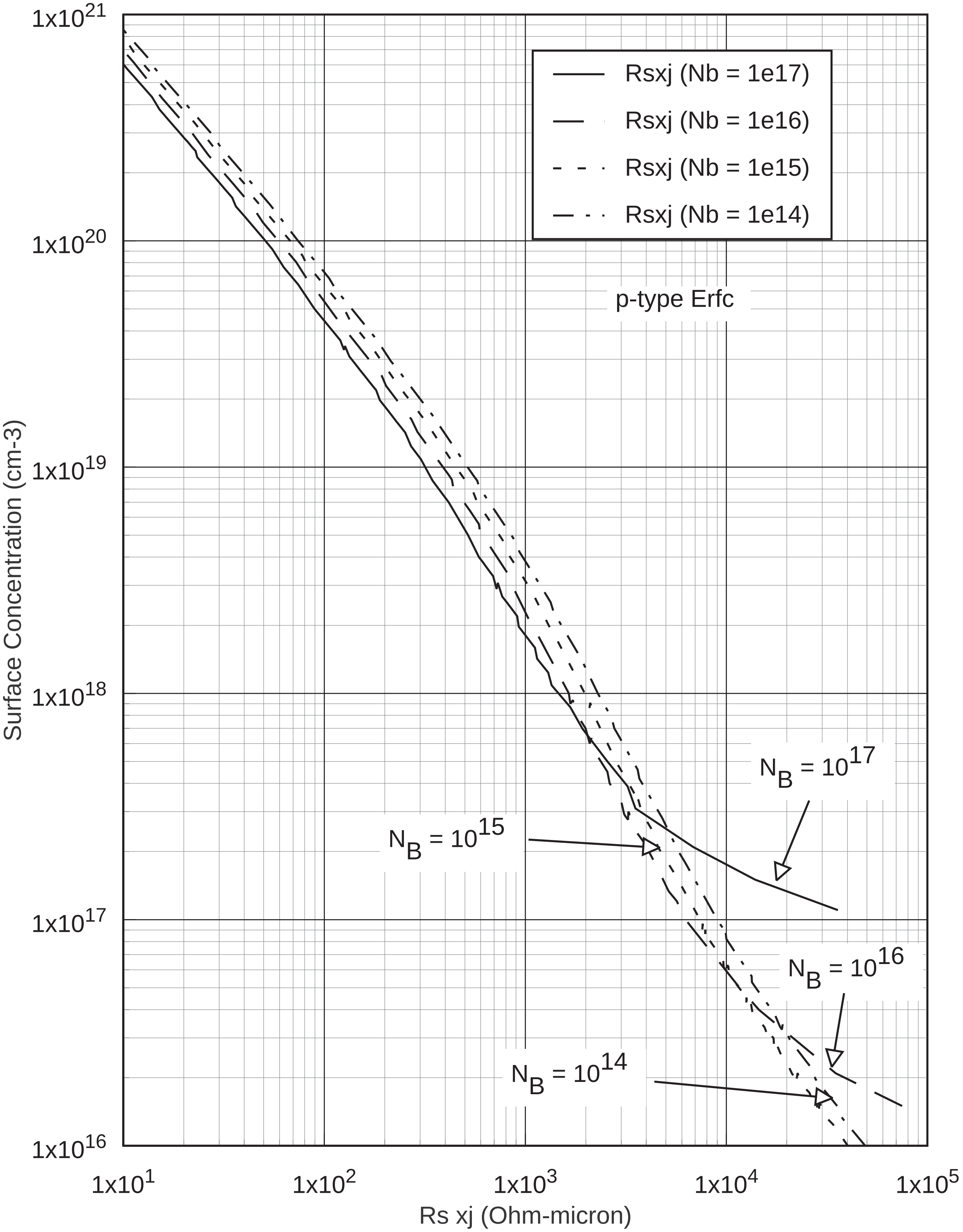


Figure 5: Irvin curve for p-type impurity, erfc profile.

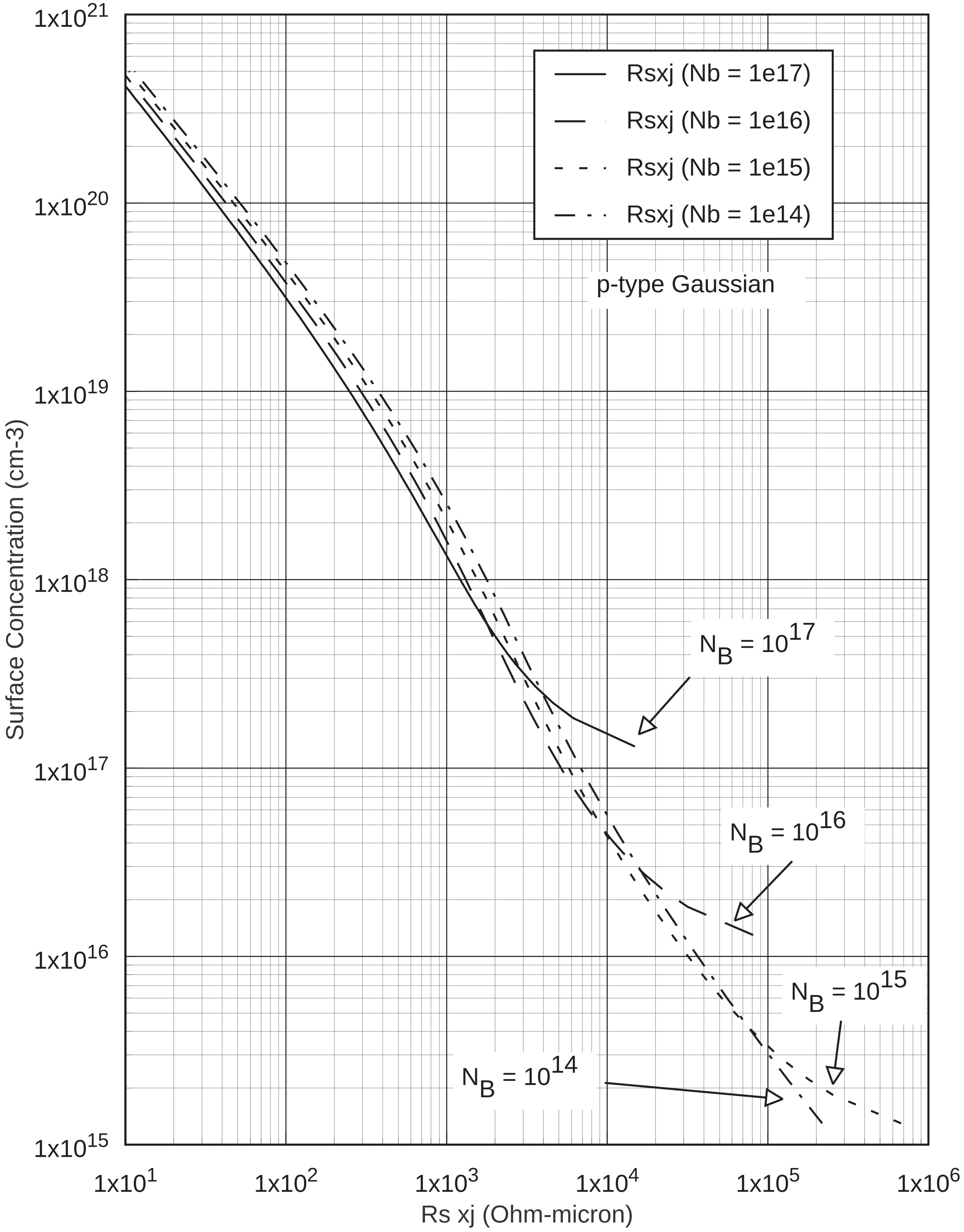


Figure 6: Irvin curve for p-type impurity, gaussian profile.

Drive-in Furnace Operating Procedure

1. Set furnace temperature controller to 100/395/100 on the 900 scale. This will achieve a temperature of 1100°C in the flat zone. Allow 30 min. for furnace to stabilize.

Step 1 should normally be performed by the lab TA before you arrive.

2. Five (5) minutes before loading wafers turn O2 gas supply ON, set for 66 with glass ball. This is to pre- fill the furnace tube with oxygen.

3. Remove furnace tube end cap and place it behind the furnace load tray. Carefully remove the pull-rod from its storage tube, and pull the wafer boat out onto the load tray. Replace pull-rod and allow 1 min. for the boat to cool.

NOTE: NEVER USE ANY PULL-ROD OTHER THAN THE ONE SPECIFICALLY FOR THE FURNACE YOU ARE USING!

4. LOAD WAFERS: Place clean Si chips in the wafer boat slots. DO NOT TOUCH THE BOAT WITH YOUR TWEEZERS.

5. Using the pull-rod, perform a slow push of the boat into the furnace flat zone. This should take approximately 1 min. The flat zone is reached when the end of the pull- rod reaches the mark on the furnace tray. Replace pull- rod in its storage tube, and loosely replace furnace end cap.

THE PULL-ROD WILL BE VERY HOT: DO NOT TOUCH ANY PORTION WHICH HAS BEEN INSIDE THE FURNACE.

6. Begin timing the drive process at the conclusion of the slow push. For normal drive-ins continue in oxygen for 5 min. At the end of 5 min., turn the O2 OFF, turn N2 ON, set for 66 with the glass ball. Continue for rest of desired drive time.

7. At the end of the drive time remove the furnace end cap and pull the wafer boat out onto the furnace tray. ALLOW BOAT TO COOL FOR 2 MIN. THE PULL-ROD WILL BE VERY HOT: DO NOT TOUCH ANY PORTION WHICH HAS BEEN INSIDE THE FURNACE.

8. Remove samples.

Store boat in furnance neck, replace cap and pull-rod, turn OFF ALL GAS SUPPLIES.

Stand-by (end of lab shut-down)

-Boat should be in the furnace neck.

-All gas supplies OFF.

-Furnace controller: 100/100/100 on the 500 scale.