

The Profiling of Polycrystalline Silicon

Can we profile "poly"? Yes, with a few qualifiers. In many cases, the profiling results are surprisingly good. Below are some examples:

A Poly Emitter

Let's consider the profile shown in Figure 1. An n+ poly layer has been deposited over a p base (in single crystal silicon). During the deposition and subsequent heat treatments, the higher concentration N+ slowly diffuses into the single crystal. On this sample, we believe that the poly-single crystal interface is at a depth of about 1600Å because we observed a faint line at that depth on the beveled surface. Conventional wisdom has it that poly tends to be evenly doped because the dopant atoms move very rapidly along grain boundaries thus resulting in a diffusivity that is a couple of orders of magnitude higher than it is for single crystal.

When we profile the sample, we convert the spreading resistance to resistivity using a calibration curve (Figure 2). Unfortunately, we don't have calibration samples for poly so we use the single crystal curves. In this case we use the <100> calibration data merely because that's what the substrate is. Once we have the resistivity, we convert it to carrier concentration using single crystal mobility data. Just how bad is this less-than-kosher profile? Well, we can check the accuracy of the resistivity by using it to calculate the sheet resistivity and then comparing this with that obtained from a four-point probe or Van der Pauw measurement. If this checks out okay, we can then look at the profile and infer a little bit about mobility. It would appear that the mobility at the interface is comparable to the single-crystal (indeed the poly layer may be nearly single crystal at the interface) and then wanders down to perhaps a fourth of that value.

The noise level appears considerably higher in the poly layer. (This doesn't surprise anyone does it?) Because of the uncertainty in mobility, carrier concentration profiles are often very fictitious and we really shouldn't plot them, but we do. On the other hand, we feel better giving you a profile of poly resistivity.

High doping concentration may help. When poly is heavily doped (which is common), the uncertainties associated with calibration and mobility are less pronounced. Note in Figure 2 that the single-crystal calibration curves for the two orientations differ by very little at the low resistivity end. We would like to think that a poly calibration curve could be some kind of average of the two single-crystal curves, and thus be fairly well defined at least at low resistivity. So maybe we can safely get from spreading resistance to resistivity. Figure 3 shows some resistivity-concentration data for p-type poly and p-type single crystal⁽¹⁾. Here again, the differences in behavior diminish as the concentration increases.

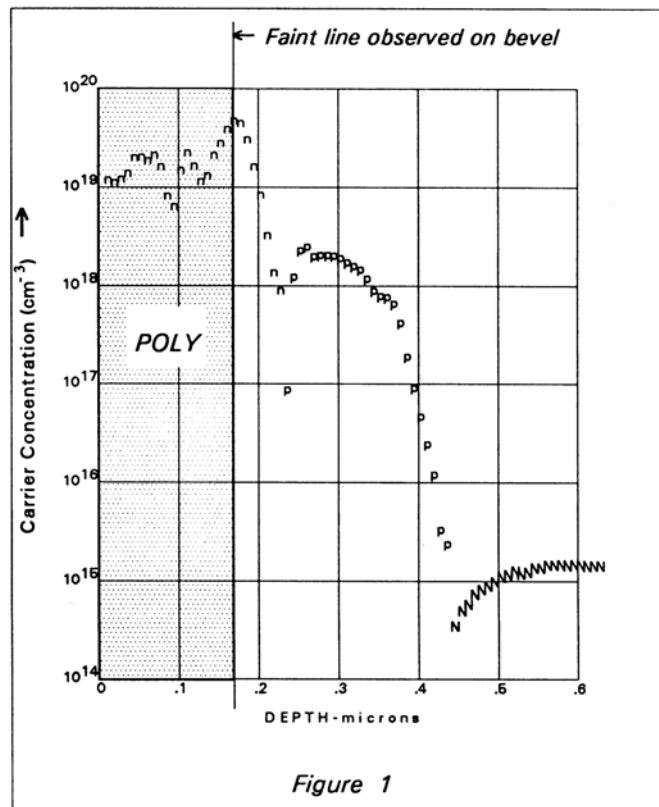


Figure 1

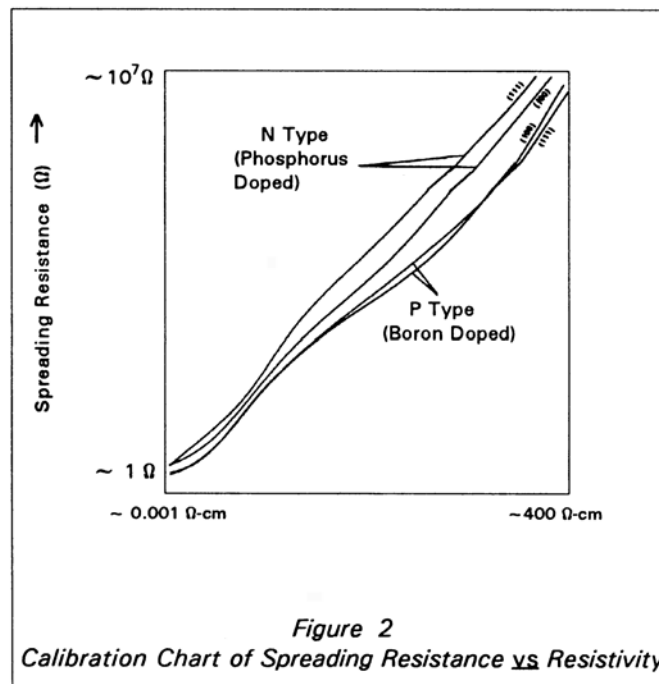
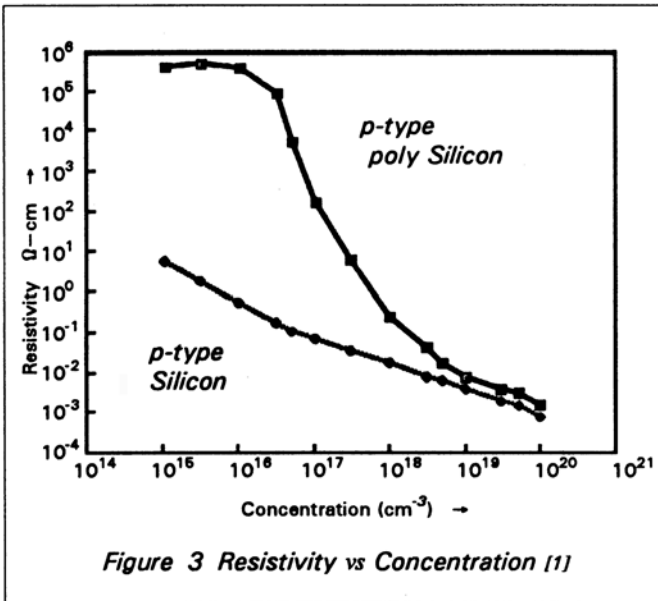
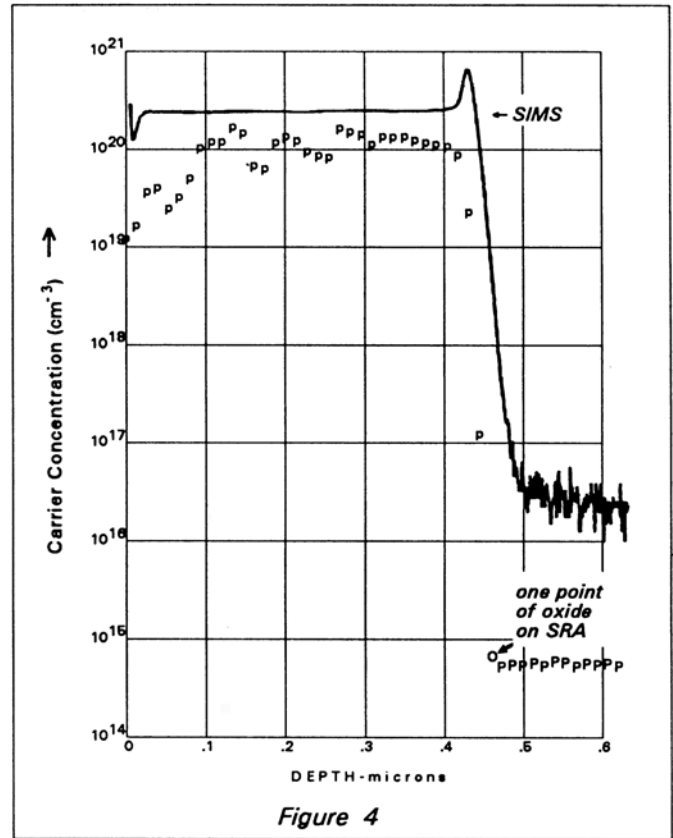


Figure 2
Calibration Chart of Spreading Resistance vs Resistivity



¹¹B+ Implant into poly over Oxide

A dose of 1×10^{16} atoms/cm² was implanted at 25 KeV and then annealed at 1200°C for 5 seconds⁽²⁾. From the SRA shown in Figure 4, the sheet resistivity was calculated to be 26 Ω/sq. The four-point probe measured it as 26.3 Ω/sq. which is excellent agreement. An estimate for the poly carrier mobility can be made by comparing the SRA profile with the SIMS.



¹¹B+ Implant into poly over Single Crystal

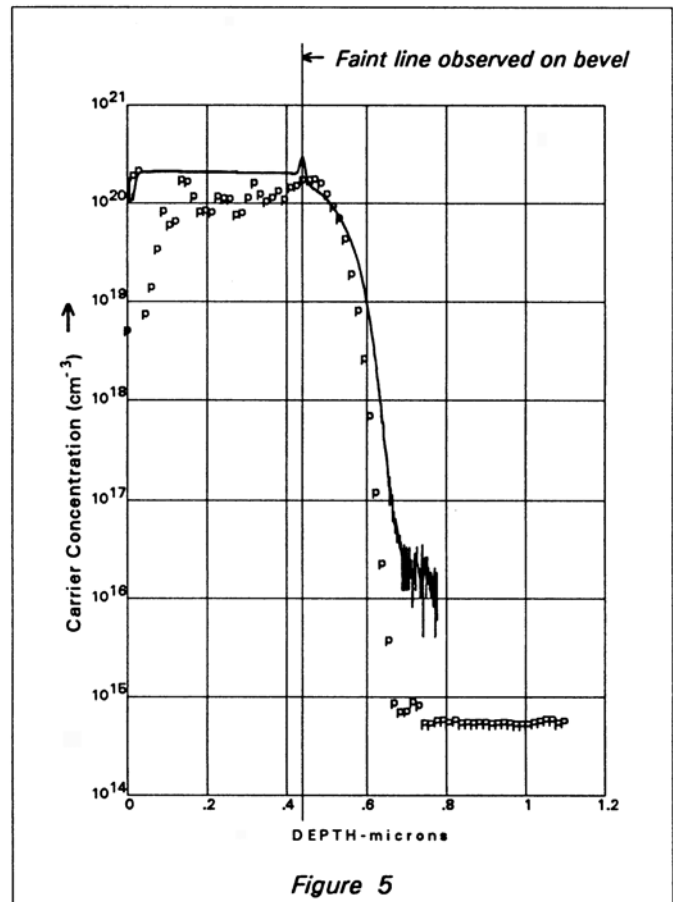
Figure 5 shows both SIMS and SRA data for the same implant and anneal into poly over single crystal⁽³⁾. The implant and annealing conditions were the same as the previous profile. Note that the SIMS profile shows a slight dip at the surface and then stays flat until the upward lurch at about 4100Å. Note also that the SRA has a much larger dip at the surface (probably low mobility) but doesn't show the spike at 4100Å. There is, however, a faint line at a Depth of 4100Å on the SRA bevel. Going deeper, SIMS falls off at a slower rate* than does the SRA – possibly due to inactive dopants in the channeling tail⁽⁴⁾.

The concurrence of events at ~4100Å is gratifying -- don't you think? If impurities like to collect at poly grain boundaries, then they would probably like to collect at the poly-single crystal interface. We see the SIMS spike, the faint line, and an apparent change in diffusivity all occurring at 4100Å which is about the right thickness for the poly layer.

The sheet rho calculated from SRA was 19.5 Ω/sq. The measured four-point probe sheet rho was 20.2 Ω/sq. After making corrections for the substrate conductivity, the "real" sheet is believed to be 21.50 Ω/sq. So the SRA sheet differs by only 7.4% - real good!

References

1. H. K. Moller and R. Podbielski, Proc. of 13th Inter. Conf. on Defects in Semiconductors, L. C. Kimerling and J. M. Parsey, Eds., Metallurgical Society of AIME (1984) 435-441.
2. Raicu, Current, Keenan, Mordo, Brennan and Holzworth, Talk: C6.5 MRS spring meeting, San Francisco, April 1990.
3. *ibid.*
4. Conversation with Michael Current at Wes Weisenberger's 1990 annual barbecue party.



*Until the SIMS profile fizzles out at about 2E16.