Epi Resistivity as an Indication of Silane Purity

A rather popular way of determining the purity of silane-type gases is to use the gas to grow an epitaxial layer on silicon and then measure the resistivity of the epi. Conventional wisdom has it that since the presence of dopant atoms lowers resistivity, a measured high value of resistivity suggests that you used high quality gases. If dopants aren't present, hopefully no other impurities will be present either. There are, however, ways to obtain high resistivity without high purity — one is to gold dope the material. (Gold doping can get you 10,000 ohm-cm but it reduces the minority carrier lifetime.) Another way to get high resistivity without high purity is to grow a polycrystalline (poly) layer (lower carrier mobility) rather than single crystal.

The resistivity of the epi layer depends on the cleanliness of the whole system — not just the gases used. It is all too easy to pick up a resistivity-lowering impurity from the susceptor (wafer holder) or the chamber itself. It is usually considered a good idea not to ever run doped material in the epi system that is to be used to determine high resistivity. After an undoped epi run has been made and measured, about all you can say is that the gases (or whatever it is that you are trying to ascertain the purity of) are at least that good. The resistivity is an inverse function of the total dopants present — not just that from the component that you are trying to measure. There is no such thing as "clean epi" — only varying degrees of dirtiness.

Just as growing less dirty epi is a problem, so is measuring it. One way to measure resistivity is with spreading resistance analysis (SRA). With SRA, you will get a resistivity-depth profile with the doping type denoted—providing the epi is dirty enough. When the resistivity gets above 5000 ohm-cm, we no longer trust our hot probe so we aren't sure of the doping type. The hot probe tends to call all high resistivity material n-type presumably because electrons have higher carrier mobility than do holes.

Also, the calibration of the spreading resistance probe gets progressively more uncertain with increasing resistivity. Take a look at the calibration chart shown in Figure 1. Note that there are four calibration curves with the P<100> and P<111> nearly coinciding but with big differences between the N<100> and the N <111>. Note the highest resistivity we have on a calibration sample is ~200 ohm-cm. Above 200 ohm-cm, we have to extrapolate. Extrapolating to say 10,000 ohm-cm is a little scary. Why don't we have calibration samples with higher resistivity? Because it is very challenging to make samples of calibration quality having higher resistivity. They tend to be highly non-uniform and unstable.

Given the difficulties, why use spreading resistance for checking epi purity? Well, as difficult as it is, everything else appears to be worse. We have been assured that voltage breakdown problems prohibit C-V measurements at high resistivity. Our four-point probe usually works well on bulk wafers up to about 10,000 ohm-cm but higher resistivities can be troublesome. For non-bulk layers, sheet resistances greater than 200,000 ohms/square can be problematic. Even if you do get a four-point probe to work (or perhaps a van der Pauw), at best you are going to get a sheet resistance (ohms per square — the average resistivity divided by the layer thickness.) But you don't want the average resistivity — you want the highest resistivity. Also, what is the layer thickness? Spreading resistance analysis is about your only hope of obtaining the layer thickness.

How high a resistivity is possible?

Well, take a look at Figure 2, "CONVERSION BETWEEN RESISTIVITY AND DOPANT DENSITY, 8-21-80" by the American Society for Testing and Materials (ASTM). The highest measured resistivity on the phosphorus curve is about 200 ohm-cm at a dopant density of about 2 X 10^{13}. The highest extrapolated resistivity on the phosphorus curve is about 4000 ohm-cm occurring at 1 X 10^{12}. (The boron curve essentially tells the same tale but is offset roughly by a factor of 3.) My old green copy of Grove gives the intrinsic carrier concentration n_i = 1.45 X 10^{10} cm^{-3} suggesting a maximum resistivity of about 280,000 ohm-cm (very much tongue-in-cheek) for silicon.

We will close this technical note by showing an example of what is considered a good test result. A piece of the wafer is beveled and probed (figure 3). The measured resistance (ohms) is collected (figure 4). The resistivity (ohm-cm) is determined (figure 5). In figure 6, the carrier concentration is calculated from the resistivity and published values of mobility (obtained from the data used in Figure 2).

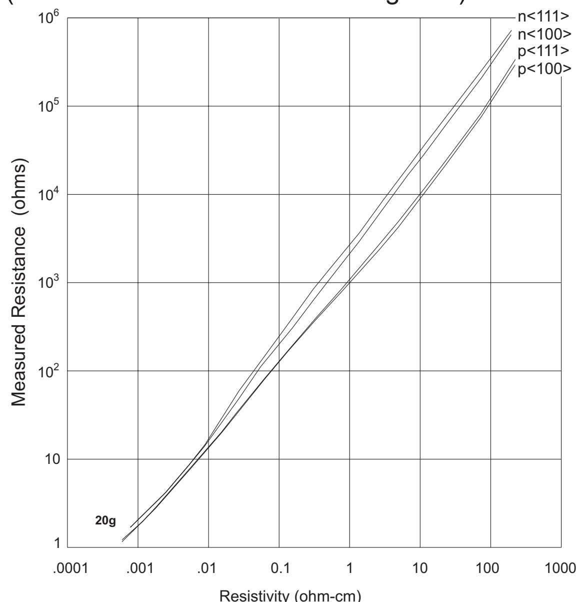

Fig 1 – Calibration Curve for a Heavily Loaded Probe

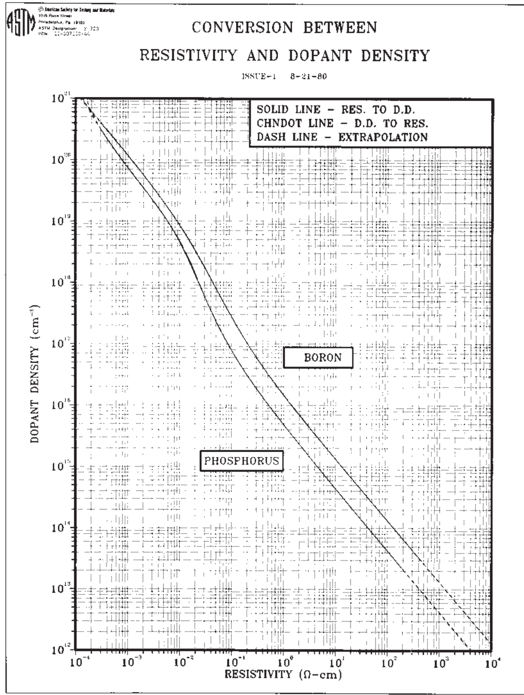

Fig 2 – The Resistivity-Concentration Curve We All Use*

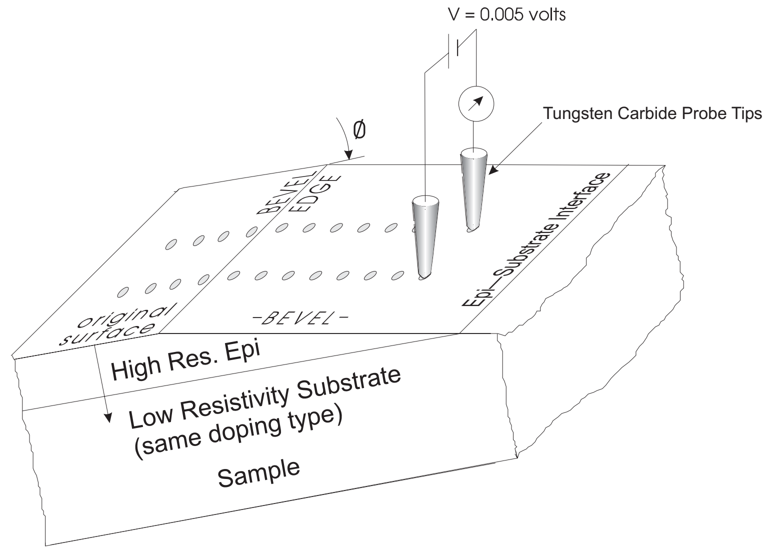

Fig 3 – The Beveled Piece Being Probed

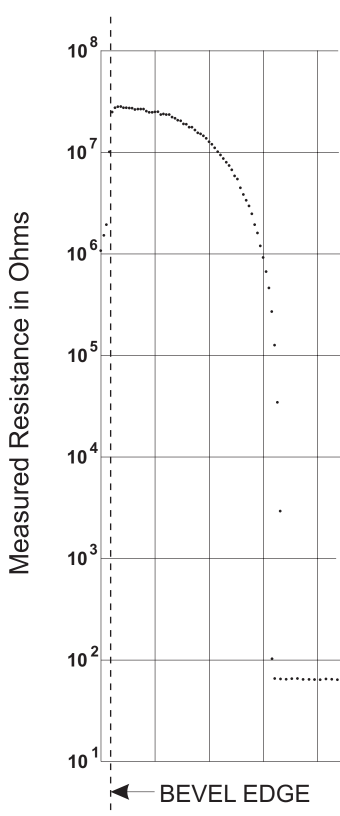

Fig 4 – Raw Data

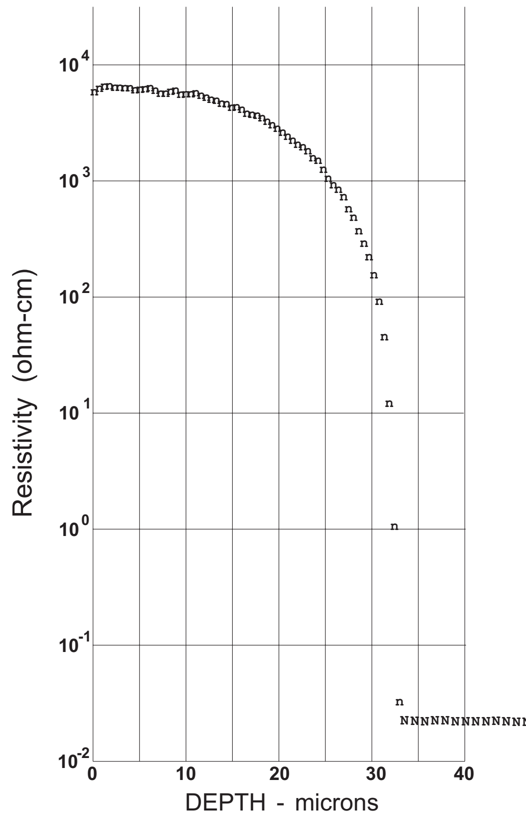

Fig 5 – Resistivity (about 8000 ohm-cm maximum)

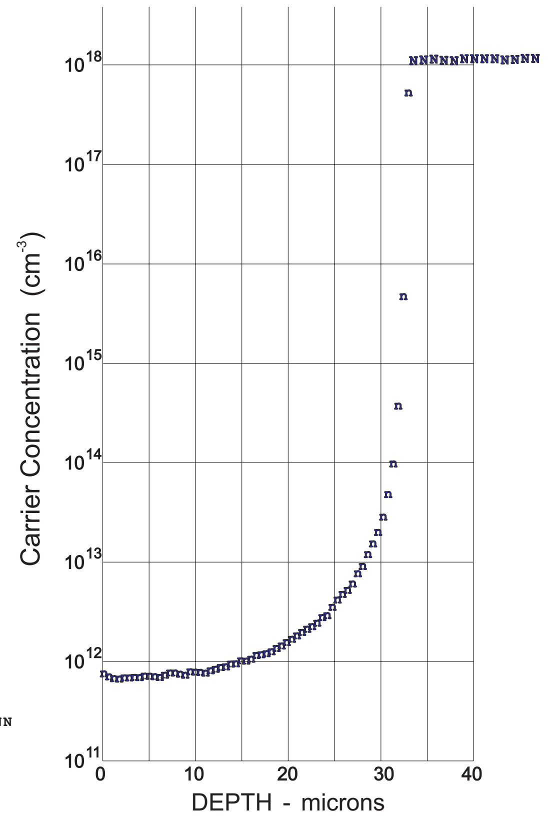

Fig 6 – Carrier Concentration

* Thurber, Mattis, Liu, and Filliben, *N.B.S Special Publication 400-64*, Table 10, p. 34 and Table 14, p. 40