RESISTIVITY FLUCTUATIONS IN HIGHLY COMPENSATED NTD SILICON*

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ABSTRACT

Calculations of the resistivity fluctuation \( \Delta \rho/\bar{\rho} \) as a function of compensation ratio in NTD-Si are presented which are valid near exact compensation. These calculations are compared with experimental data taken on silicon which has been compensated by the NTD process to resistivities as high as 100,000 \( \Omega \)-cm. Calculations are also presented of the maximum possible mean resistivity obtainable before fluctuation induced type conversion occurs as a function of the initial starting material resistivity fluctuation.

1. INTRODUCTION

Janus and Malmros have given expressions to predict the effect of transmutation doping on the relative impurity concentration fluctuation.\(^1\) They have shown that for n-type NTD-Si doped well beyond exact compensation, the relative concentration inhomogeneity decreases linearly with increasing fluence (doping factor). For many envisioned detector applications, it is desirable to use the NTD-process to compensate to very high resistivities near exact compensation. Several attempts to transmutation compensate p-type float zone silicon to very high resistivities for various detector applications have been reported.\(^2-4\) The usefulness of this material is thought to depend on the final resistivity uniformity which can be achieved. It is clear that this uniformity is not linear with fluence near exact compensation due to the impor-
tance of the intrinsic carrier concentration. It is, therefore, desirable to obtain expressions for uniformity as a function of fluence or compensation ratio for p-type as well as n-type material near exact compensation. It is also desirable to express this uniformity in terms of resistivity rather than impurity concentration since the wafer uniformity is always determined experimentally by spreading resistance or four-point probe resistivity measurements, not impurity concentration. It will be shown that NTD compensation yields a significant improvement in resistivity uniformity compared to conventional compensation by melt doping with phosphorus in the range of compensation ratios useful for extrinsic silicon IR detector applications.

2. A RESISTIVITY FLUCTUATION MODEL

In general, the resistivity as measured by one of the usual probe techniques is a complicated function of the probe coordinates on the surface of the wafer. An exact definition of mean resistivity and deviation from this mean is therefore hopelessly complicated from an experimental point of view. An inspection of typical radial traces of spreading resistance fortunately shows that the periods and amplitudes of the observed fluctuations due to doping inhomogeneities are usually rather well defined. In fact, the obvious periodicity of these traces has lead Voltmer and Ruiz to apply Fourier analysis to these patterns. They find that the Fourier transformed patterns contain relatively few dominant spatial frequencies which they have been able to relate to ingot pulling speed and rotation frequency.

Because of the amplitude uniformity usually found in spreading resistance traces, it is possible and desirable to define the mean of the maximum and minimum resistivities, $\bar{\rho}$, and the maximum fluctuation, $\Delta \rho$, as

$$\bar{\rho} = \frac{\rho_{\text{max}} + \rho_{\text{min}}}{2} \quad (1)$$

and

$$\Delta \rho = \rho_{\text{max}} - \rho_{\text{min}} \quad (2)$$

where these maximum and minimum resistivities are analogous to the minimum and maximum concentrations discussed by Janus and Malmros. By calculating these two resistivities as a function of fluence (or compensation ratio), contact between experiment and theory can easily be made.