Profiling of Lithium and Potassium into Silicon

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Abstract

The profiling of Lithium and Potassium into Silicon doped by electro deposition from molten salts (LiBr, KI) has been studied for various time periods and deposition currents. For the samples studied, changes in the deposition time and current have significant effects on the conductivity type and sheet resistance variation. This has been attributed to the high value of solid solubility of Lithium and Potassium in Silicon. Additionally, surface concentration variation with depth is affected significantly by variation in deposition time, particular for samples with a deposition time of 7 minutes. A junction was found 156 microns from the surface.

For constant deposition current diffusion profiles, show two distinguishing regions; one with large diffusivity and the second with a small diffusion constant.

Key Words: Semiconductor, Diffusion, Sheet resistance, Surface concentration.

1. Introduction

It is well known that the characteristics of a crystal can be changed quite dramatically by adding chemical impurities into a semiconductor crystal. In order to introduce impurities into a semiconductor, several methods have been tried [1–8], and almost all of these techniques are sophisticated devices or expensive. In the search for new, less expensive techniques, we found that electrolysis doping from molten salt is the most successful [7, 8].

During the electrolysis, the metals layer deposited on the surface of the sample is able to overcome the barriers and diffuse into a crystal [7]. The aim of this investigation was to study the profiling variation of Lithium and Potassium into Silicon, as a function of deposition time and current, using the electrodeposition of impurities from molten salt (LiBr, KI). Annealing was not performed subsequent to electrode position. Sheet resistance was measured by the four–probe method, which permits determination of the electrically active dopant atom distribution as a function of depth in a doped sample, for various deposition times and currents. We have been able to measure the changes in type and value of electrical conductivity when the compensating Lithium and Potassium atom concentration increased.

2. Experiment

In this work, a p-type silicon sample of 6 cm is used as the cathode and a piece of tantalum as the anode, and both are immersed in molten salts (LiBr, KI) used as the electrolyte. This experimental protocol has been previously described [8]. Penetration profiles were determined by means of serial sectioning, using

precision chemical etching. The system was initially calibrated by the weight-loss method using a Mettler M7 microbalance. Sheets were measured at various depths of the doped samples by stripping layers of Silicon. Detailed data on variation of sheet resistance, as a function resistance of depth, was measured by the four-probe method for a large number of steps. Surface concentration of electrically active atoms is calculated from the relation [11]

$$N_s = \frac{1}{R_s\,\mu\,q}.$$

where Rs is the sheet resistance in ohms, μ is the free carrier mobility in cm^2 V^{-1}s^{-1}, and q is the electron charge in coulombs.

For the present study, lithium and potassium was chosen as donor impurities because of their high solid solubility and diffusivity (6 x 10^{19}cm^{-3}, 7 x 10^{-6} cm^{2}s^{-1}for lithium and 9 x 10^{18} cm^{-3}, 5 x 10^{-7} cm^2 s^{-1} for potassium). A review of the literature suggests that the present investigation is probably the first to employ this technique for the study of net surface carrier concentration profiles in silicon doped by electrodeposition from salts.

3.   Results and Discussion

Figures 1 and 2 show the variation in sheet resistance as a function of deposition time for various deposition currents, and show that the effect of deposition current on doped samples is significant. For the samples studied, the changes in the conductivity type from p to n-type, even with short deposition time ($\geq$ = 7 min) and the high current used (>15 mA), is due mainly to the complete compensation of boron atoms at the surface of the silicon. As the deposition time increased, sheet resistance per unit area decreased, indicating an increase in the occupation of substitution sites in the silicon by the lithium and potassium atoms.
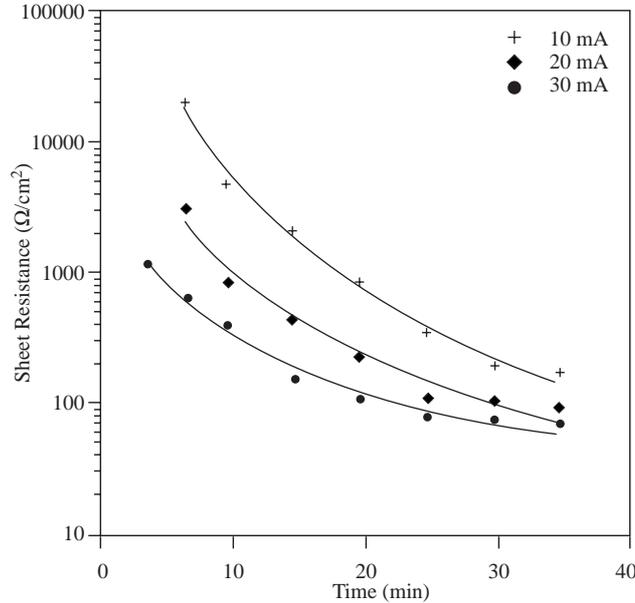
Figure 1. Variation of sheet resistance with deposition time at different deposition currents using molten KI salt.

Figures 3 and 4 provide profiles for carrier concentration with deposition time. These results have been derived from Figures 1 and 2 for the same samples and are consistent with the discussion above; decrease in sheet resistance with increase in deposition time and currents are primarily due to the corresponding

increase in the carrier concentration. The smooth curve drawn through the experimental points shows that the lithium and potassium diffusion profile in silicon can be divided into two parts, distinctly showing an initial increase of surface concentration followed by a region where concentration remains steady. A possible explanation for this surface concentration variation can be given as follows: n-type doping is diffused in a p-type substrate above the surface and is then driven in where they compensate for the boron atoms. A short deposition time limits the number of deposited atoms, which increase with deposition time. Alternately, increasing the deposition current will allow more doping atoms to contribute to the surface concentration, as shown in Figure 5. Figures 6 and 7 show the experimentally determined potassium diffusion profiles. For a short deposition time (7 min), a junction depth of approximately 150 microns is indicated. When increasing the deposition time without changing the deposition current, no junction is noticed, even at depth of 250 microns, and concentration appears to be steady.
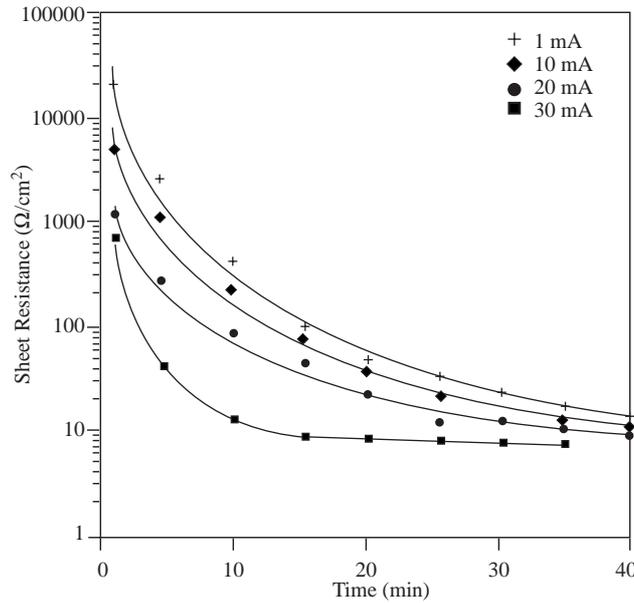
Figure 2. Variation of sheet resistance with deposition time at different deposition currents using molten LiBr salt.
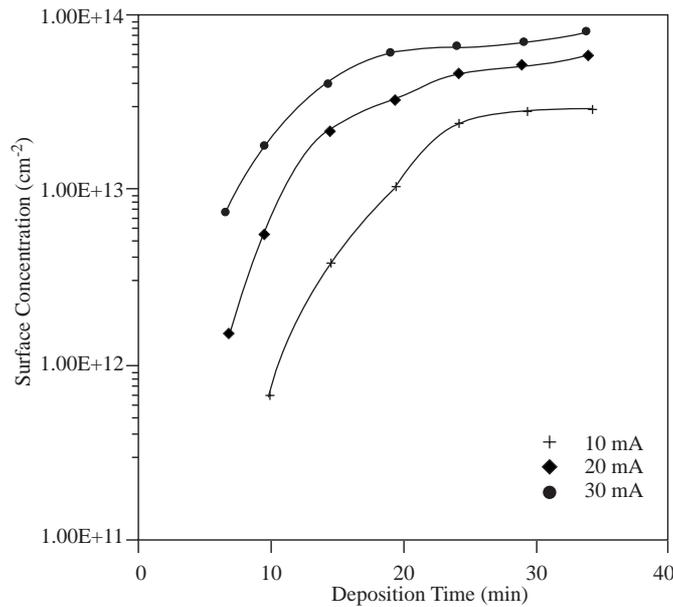
Figure 3. Surface concentration with deposition time at different deposition currents using molten KI salt.
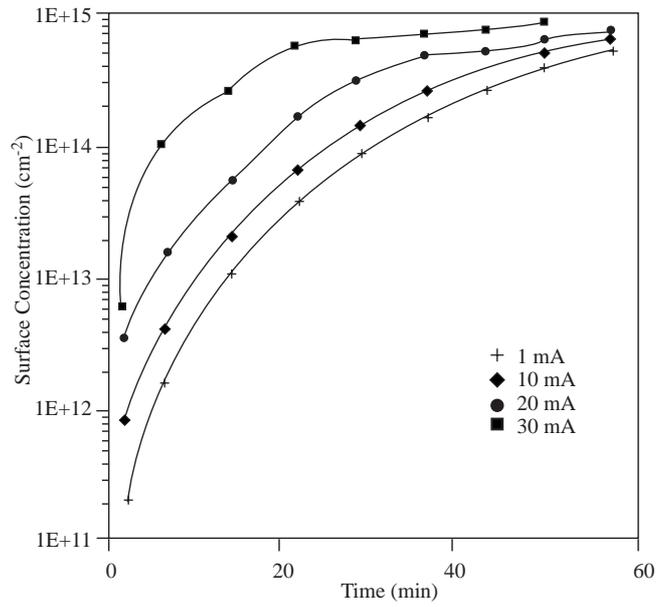
Figure 4. Surface concentration with deposition time at different deposition currents using molten LiBr salt.
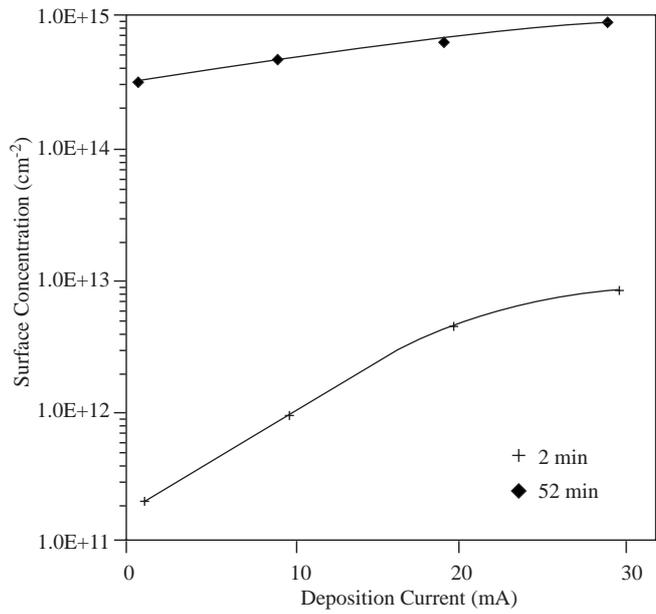
Figure 5. Surface concentration as a function of deposition current for different deposition times.
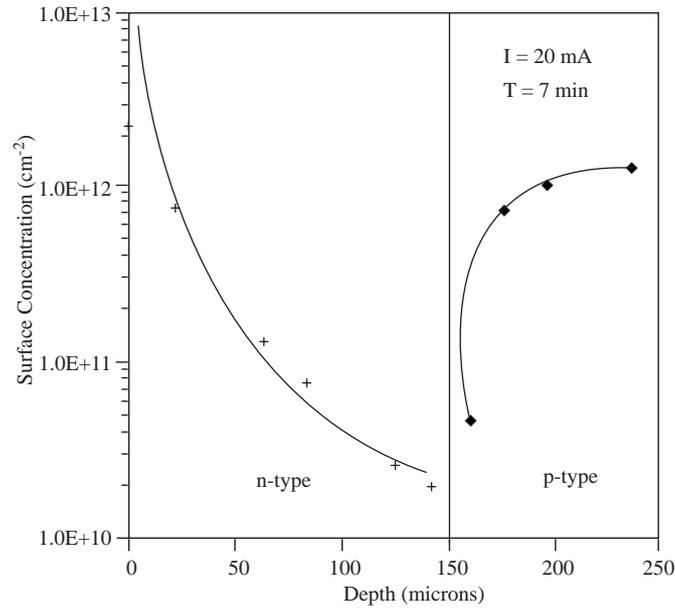
Figure 6. Surface concentration as a function of depth using KI salt with deposition time of 7 min.
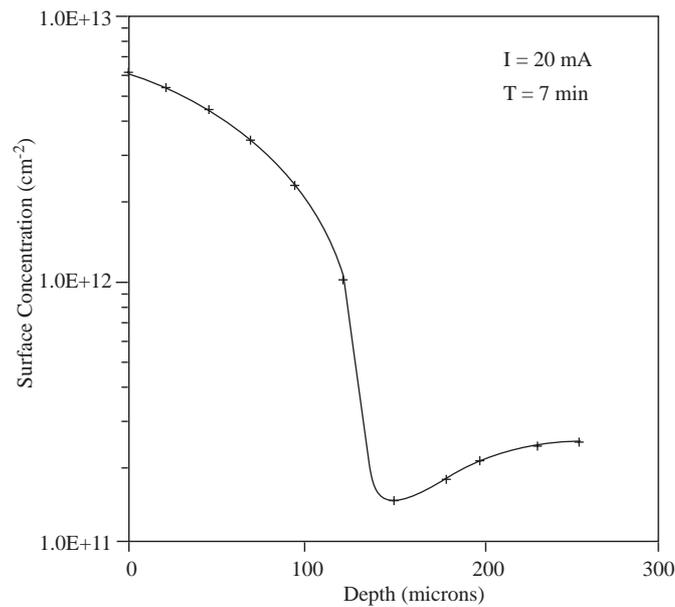
Figure 7. Surface concentration as a function of depth using KI salt with deposition time of 10 min.

4.   Conclusions

The following conclusions may be drawn from the results obtained: 1. For the samples studied, changes in deposition time and current have a significant effect on both the type of conductivity and variation in sheet resistance; 2. Surface concentration variation with depth is significantly affected by variation in deposition time. In particular, for the sample with a deposition time of 7 min, a junction was found to be 150 microns from the surface; 3. Diffusion profiles show two distinguishing regions, one with large diffusivity and the second with a small diffusion constant.

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