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AIR FORCE/ION PHYSICS HARDENED
LITHIUM DOPED SOLAR CELL DEVELOPMENT

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I. INTRODUCTION

Ion Physics Corporation (IPC) is working under Air Force Contract F33615-70-C-1491 to develop a lithium-doped solar cell hardened against both space radiation and nuclear weapons burst environments. Performance objectives for the hardened cell are sufficiently severe that they are not met by any of the lithium cells which have been reported on to date. IPC is developing a cell structure designed to meet these program goals. The first 12 months of the 24-month program have involved development of elements of the cell structure. The completed structure is now to be assembled and optimized.

II. THE IPC CELL STRUCTURE

Because the performance characteristics of the lithium-doped solar cell are determined by the concentration profile of lithium throughout the cell, IPC is attempting to develop a structure allowing independent control over profile shape in the base, concentration in the base and profile in the vicinity of the junction.

The IPC cell is illustrated in Fig. 1. The cell is 10 mils thick and has 5- μ m aluminum contacts. Base material is 20 Ω -cm phosphorus-doped silicon with <100> orientation. The cell is a P⁺ N⁺ NN⁺ structure in which the N⁺ phosphorus-doped region completely encloses the base N region. Purpose of the N⁺ region at the front below the P⁺ layer is to reduce diffusion of lithium into the P⁺ layer and to prevent widening of the space charge region due to lithium depletion after irradiation.

The N⁺ layer at the cell back prevents outdiffusion of lithium and insures low resistance ohmic contact.

The cell is fabricated in the following sequence:

- (1) The silicon wafer is diffused at 1000°C with PH₃ to produce the back N⁺ layer.
- (2) The front P⁺ layer is produced by diffusion at 950°C with B₂H₆.
- (3) The cell is sized using an orientation dependent etch which leaves <111> planes as the cell edges.
- (4) Phosphorus is ion implanted from the front to produce the buried N⁺ layer which also extends down the cell edge surfaces.
- (5) Lithium is introduced through the back surface by ion implantation and is distributed through the cell using conventional elevated temperature distribution cycles.
- (6) Aluminum contacts and antireflection coating are applied.

A. Lithium Implantation

Implantation of the lithium is fundamental to the IPC cell design. In the implantation process a high energy beam of the desired ion is formed, analyzed and rastered over the surface to be

implanted. The number of ions introduced is measured directly by integration of total charge collected at the substrate. Typically IPC used 250 keV Li^7 which penetrates approximately $1 \mu\text{m}$ into the silicon.

Implantation of the lithium offers many important advantages over other lithium introduction techniques:

- (1) The amount of lithium introduced is precisely controlled and is uniform and reproducible.
- (2) The amount of lithium introduced is independent of the distribution temperature.
- (3) No surface treatment is required after implantation as there is no surface residue, surface etching or pitting.

Following implantation, the lithium is distributed using distribution cycles approximately equivalent to those employed with diffused lithium cells. During distribution a large portion of the implanted lithium is lost from the back surface of the cell. The N^+ barrier layer at the back surface into which the implant is made reduces this loss by more than an order of magnitude. Shown in Fig. 2 are experimental lithium profiles after distribution at high temperature of cells with and without the N^+ barrier. Because IPC is able to "count" every lithium ion introduced into the cell, it is possible to determine from each profile a "utilization fraction," f , which is the fraction of initially implanted lithium remaining after distribution. Typically for implants at 250 keV into the N^+ barrier with distribution times of the order of hours at 450°C or below this fraction ranges between 0.02 and 0.03.

Desired cell base lithium concentrations averaging slightly above 10^{16}cm^{-3} are obtained by implanting 1×10^{16} lithium ions cm^{-2} . This level can be produced in about 2 min per cell from the IPC research implantation facility. As seen in Fig. 3, the lithium concentration throughout the base can be varied almost linearly with implant fluence.

The N^+ layer at the back surface into which the lithium implantation is made has an additional important function. Ion implantation into a crystal lattice causes structural damage which for most applications is then annealed at elevated temperatures typically in the range of 700°C and above. When lithium is implanted into silicon, the lattice damage which occurs is not completely annealed at temperatures below 450°C . Short 5-min anneals at 700°C are sufficient but could cause reproducibility problems with the lithium profile. If the implantation is made into $20 \Omega\text{-cm}$ silicon without an N^+ surface layer and adequate anneal is not provided, the resulting solar cell has high series resistance of several ohms. However, when the implant is made into the heavily doped N^+ layer,

it is found that no anneal is required to insure good ohmic contact and low series resistance.

B. The Implanted Phosphorus Front Barrier

In order to reduce lithium diffusion into the P^+ region and to prevent widening of the junction space-charge region due to lithium depletion after irradiation, IPC will implant a thin N^+ phosphorus layer immediately below the front P^+ layer. Without this N^+ barrier it is possible to control shape and concentration of the lithium profile through the base but desired control over the lithium profile in the junction vicinity is dependent upon use of the barrier. This barrier is the only component of the planned structure on which development has not yet been successfully completed.

Desired concentration profiles near the junction are illustrated in Fig. 4. Phosphorus is implanted at 200 to 300 keV to penetrate approximately $0.15 \mu\text{m}$ below the junction and to produce a peak concentration of approximately 10^{16}cm^{-3} . The phosphorus N^+ region below the P^+ surface layer is to act as a barrier to reduce loss of lithium into the P^+ layer sink during distribution and consequently to provide control of the lithium level. Peak concentration in the N^+ layer is selected to be approximately equal to the lithium level in the vicinity of the junction and should serve as a barrier to lithium diffusion until concentration reaches this level. If the phosphorus concentration is made much higher than the required lithium level, the N^+ region will retard flow of holes to the junction and will reduce cell performance.

Investigation of the front barrier is proceeding. Results to date have been inconclusive. With a few exceptions, cells having the front barrier have shown losses in V_{oc} of 30 to 100 mV relative to otherwise identical cells without the barrier. Some cells have shown evidence of high junction vicinity lithium concentration and low concentration gradient, but these results have not been consistent or reproducible.

III. PRESENT STATUS

A first lot of 110 crucible-grown silicon cells has been fabricated without the front N^+ barrier. Lithium implant fluence was $1 \times 10^{16} \text{cm}^{-2}$ at 250 keV followed by 450°C 120-min distribution. Layer stripping showed lithium utilization fraction of 0.028 with a profile peak of $1.3 \times 10^{16} \text{cm}^{-3}$. Median maximum power of these 10-mil thick aluminum contacted cells was 58 mW.

Introduction of lithium by ion implantation eliminates reproducibility and surface problem deficiencies of other introduction techniques. Implantation has been demonstrated to make possible a degree of control over the cell lithium content which has not previously been available. Front barrier development remains to be completed. Successful development of the barrier will make available the freedom to select optimum lithium concentration throughout the cell, including in the vicinity of the junction.

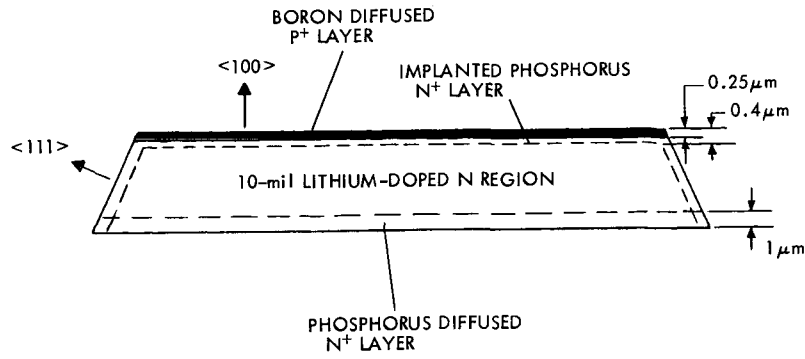


Fig. 1. Ion Physics Corp. lithium-doped cell

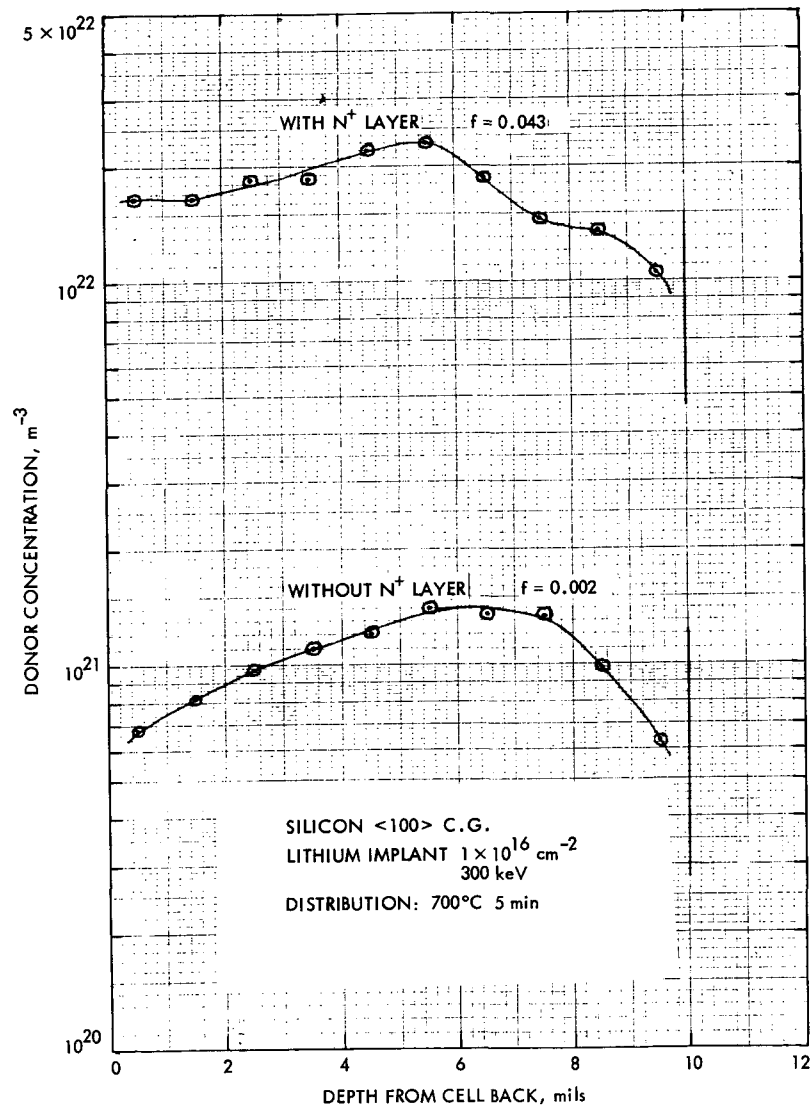


Fig. 2. Effect of back N⁺ layer on lithium profile

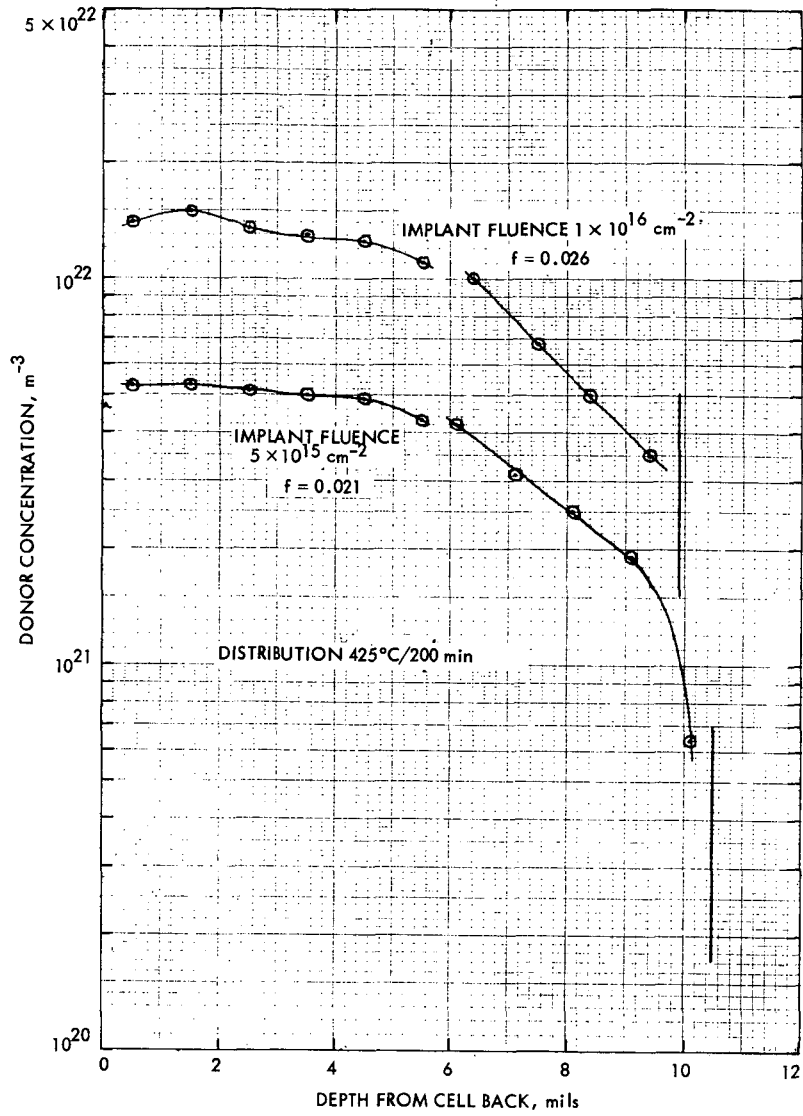


Fig. 3. Effect of implant fluence on profile

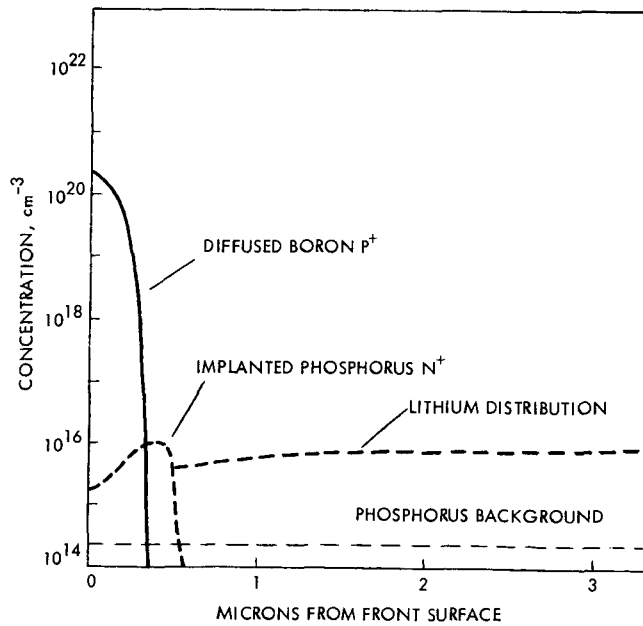


Fig. 4. Planned concentration profiles