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USE OF LOW-ENERGY HYDROGEN ION IMPLANTS IN HIGH-EFFICIENCY CRYSTALLINE-SILICON SOLAR CELLS

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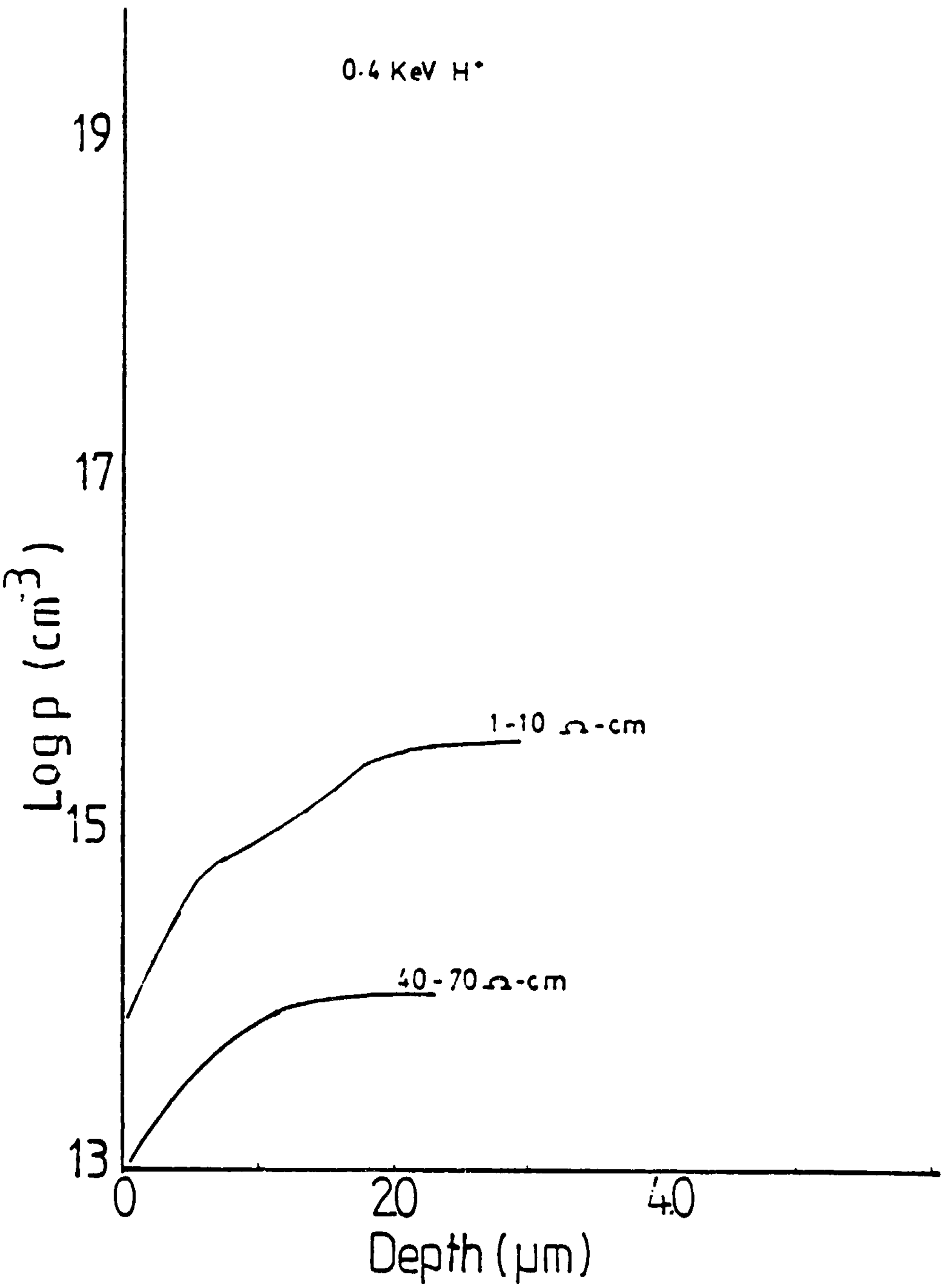
Basic Effects of Low-Energy H^+ Implants

A. BORON NEUTRALIZATION
B. EFFECT ON ELECTRICALLY ACTIVE METALLIC IMPURITIES
C. PASSIVATION OF DANGLING BONDS
D. DEEP PERMEATION
E. HYDROGEN CAUSED DAMAGE - SYNERGISTIC EFFECTS

Effects of Low Energy H^+ Implants on Solar Cell Behavior

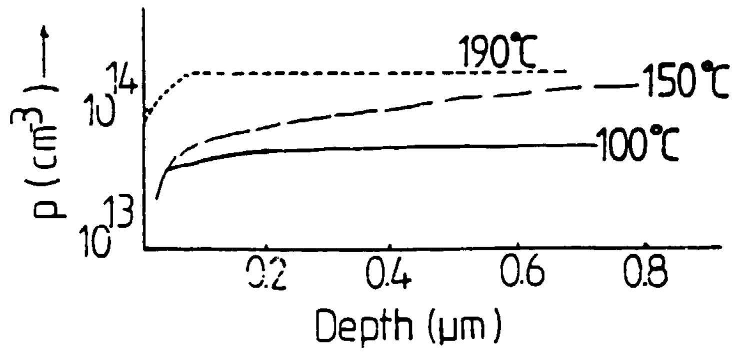
A. EFFECT ON BASE
B. EFFECT ON SPACE CHARGE LAYER
C. EFFECT ON EMITTER

Hole Concentration Profiles (Moderately Doped p-type Si)



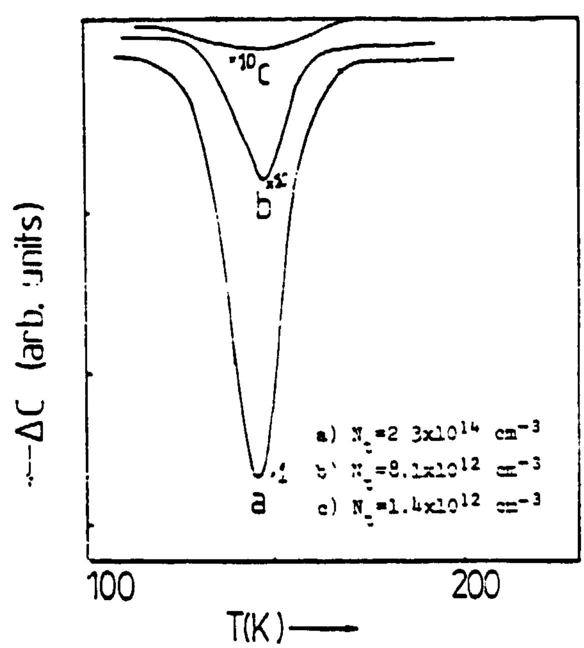
Spreading resistance plots showing the hole concentration in moderately doped ($10^{15}cm^{-3}$ and $2x10^{14}cm^{-3}$) p-type Si samples after exposing them to 0.4KeV H^+ ions for 1 minute. The incident fluence of H ions was 10^{18} cm^{-2}.

Hole Concentration Profiles (B-doped p-type Si)



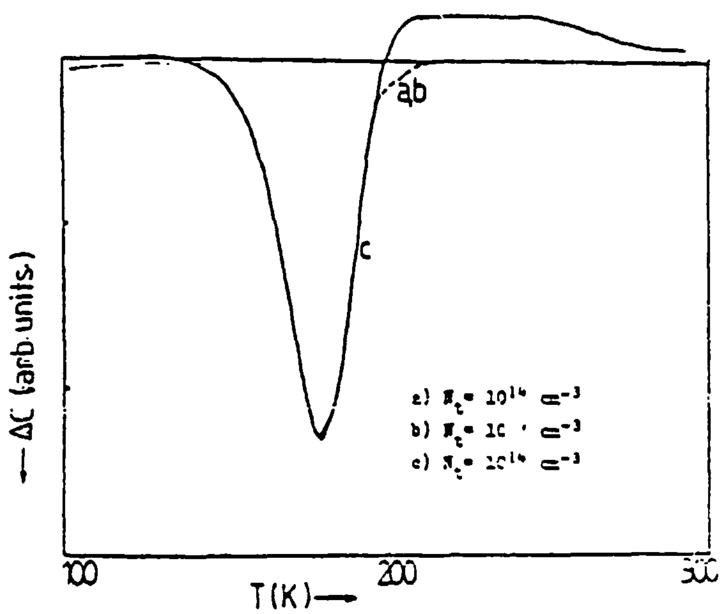
Hole concentration in H-ion-bombarded p-Si doped with 2×10^{14} cm^{-3} boron atoms after annealing for 1 hr at the temperature shown. Note that a 190 °C heat treatment anneals out all the compensating defects at the surface.

Deep Level Transient Spectra (Cr-doped p-type Si)



Curves showing the DLTS spectra obtained from Schottky-diodes made on Cr doped p-Si as a function of processing; a) no treatment. b) 300 °C 1hour anneal in an inert ambient. c) 0.4KeV H^+ implant for 5 minutes. Note that although the concentration of the Cr levels decreases after both heat treatment and after IB bombardment, the reduction is much more pronounced in the latter case.

Deep Level Transient Spectra (Ti-doped p-type Si)

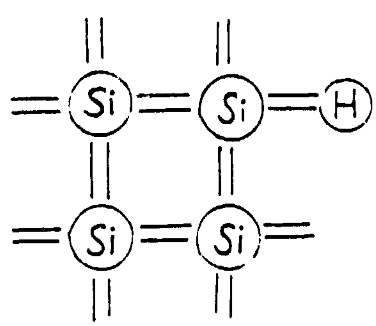


Curves showing the DLTS spectra obtained from Schottky-diodes made on Ti doped p-Si, as a function of processing; a) no treatment. b) 300 °C 1hour anneal in an inert ambient. c) 0.4KeV H^+ implant for 5 minutes. Note that the concentration of the Ti levels is insensitive to these processes.

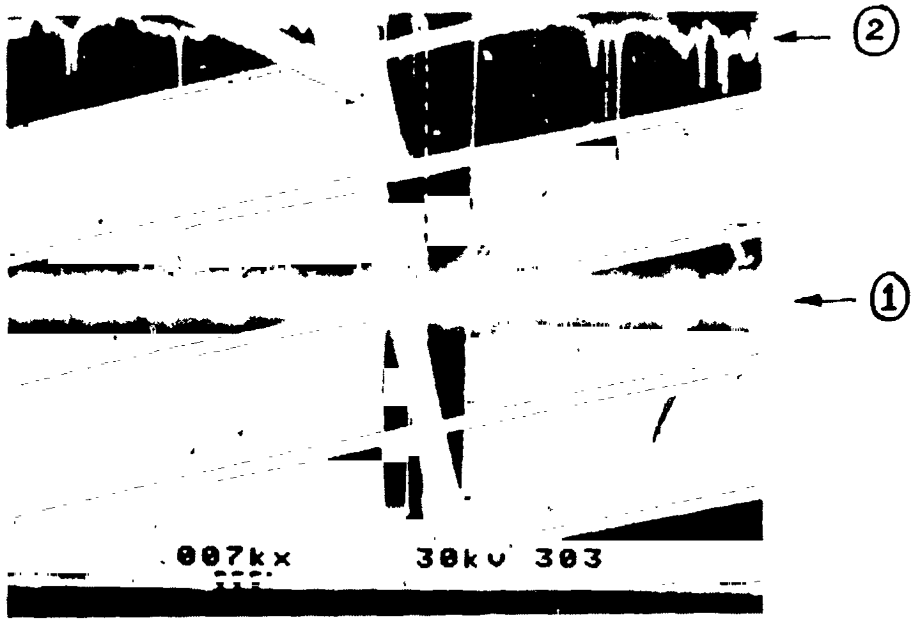
Data from DLTS Spectra Establish that H^+ Low-Energy Implants:

A. DEFINITELY DO NOT AFFECT ALL METALLIC DEEP LEVELS.
B. ONLY AFFECT THE LEVELS OF FAST DIFFUSERS.
C. PASSIVATION OF FAST DIFFUSERS? ENHANCED DIFFUSION OF FAST DIFFUSERS (DUE TO RADIATION) AND GETTERING?

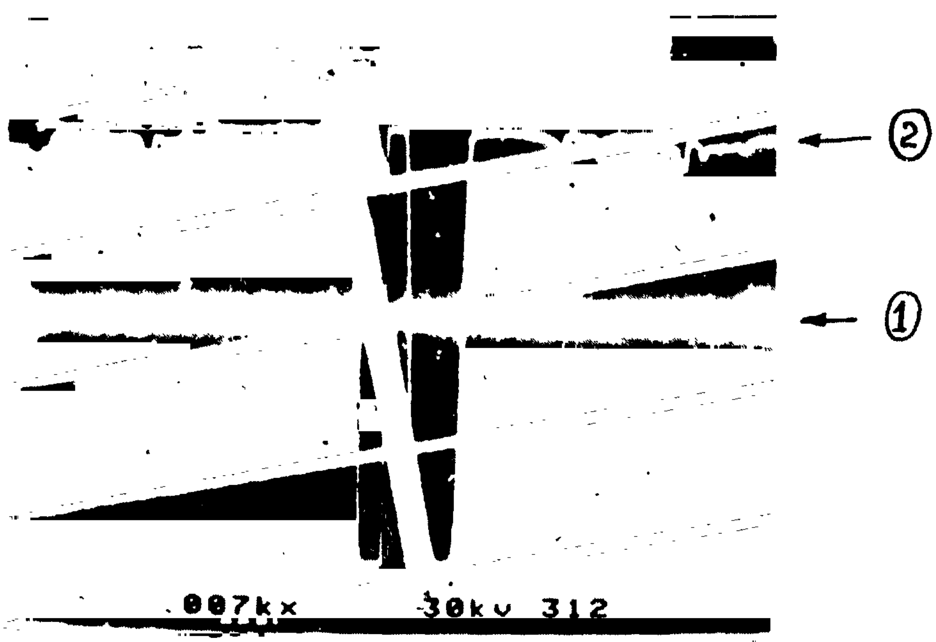
Passivation of Dangling Bonds



Electron Beam Induced Current Scans

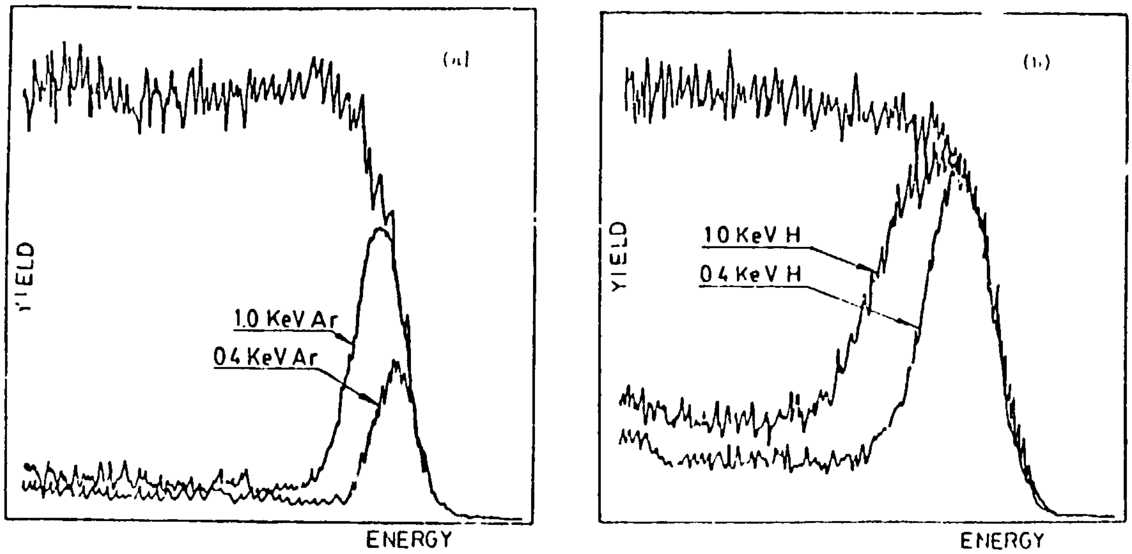


EBIC Scans taken on the front surface before any H+ treatment



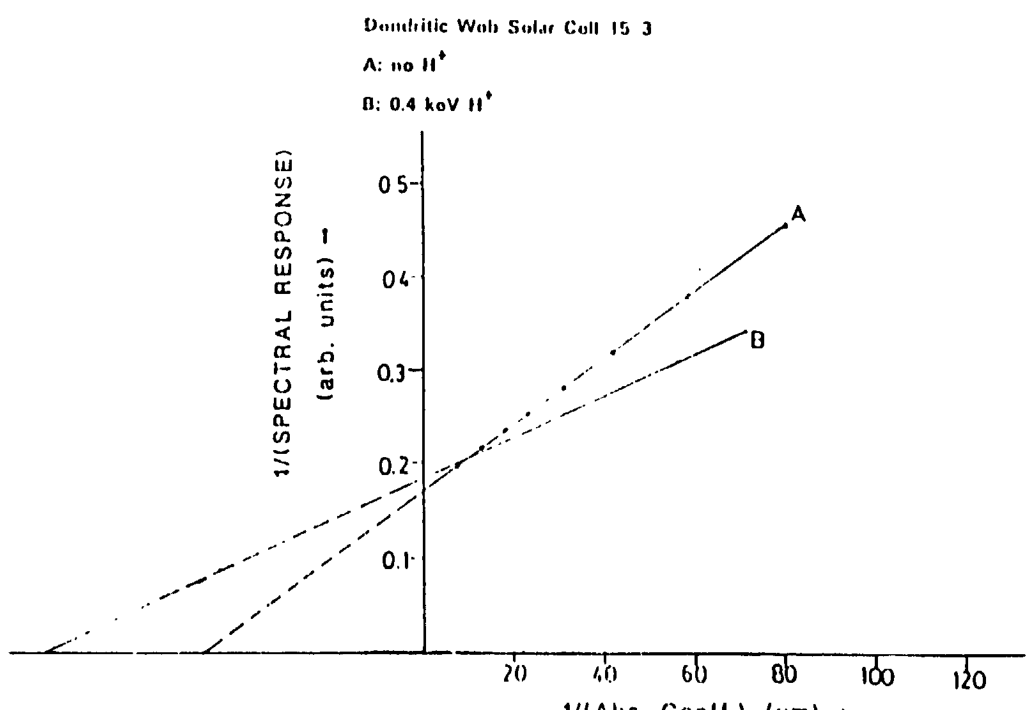
Scans taken on the front surface after implanting the device with H+ on the back of the wafer

Rutherford Backscattering Spectra

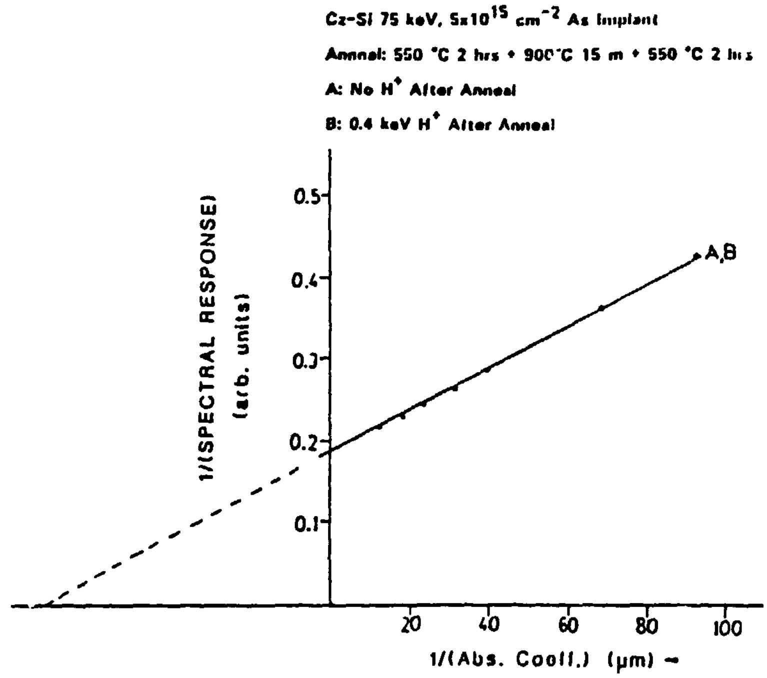


Rutherford backscattering data in the channeling and random mode from Si samples subjected to low-energy ion-beams. Note that as the energy of the incident ions is increased, more damage is introduced at the Si surface. Further, note that H ions introduce more lattice damage than Ar ions.

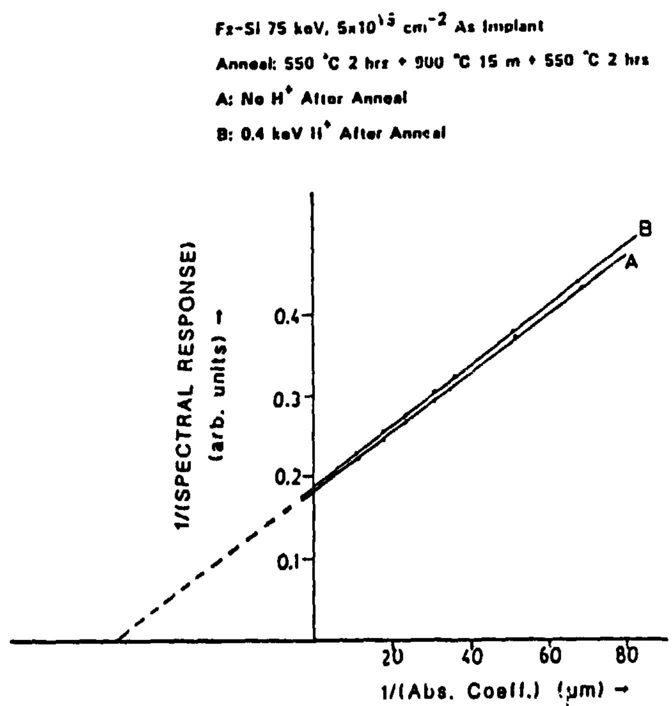
Spectral Response



Spectral Response



Spectral Response



Effect of H on Space Charge Region of Solar Cells

Device	L_n Before H^+	L_T After H^+	I_o before H^+ (A/cm^2)	I_o after H^+ (A/cm^2)	I_o base (A/cm^2) Theoretical
S7 Cz-Si	75	75	3.096×10^{-9}	6.47×10^{-11}	1.1×10^{-11}
S25 (Fz-Si)	51	51	1.667×10^{-9}	1.57×10^{-10}	10^{-12}

Total Saturation Current and Saturation Current Component Due to Emitter Transport for Different Devices

Processing	J_o (pA/cm^2)	J_{oe} (pA/cm^2)
4412-5C as is	3.78	1.71
4412-5C no oxide	7.13	5.06
4412-5C no oxide after H^+	3.90	1.83

$J_{ob} = 2.07 \times 10^{-10}{}_{\cdot}{}^{2}$ A.cm^2

Surface Recombination Velocity Values for Different Devices

Model	S_p with oxide	S_p no oxide	S_p no oxide with H^+
Roulston	1.53×10^4	5.66×10^4	1.65×10^4

J_{oe} (with oxide) $= 3.786 \times 10^{-12}$ A.cm^2.

J_{oe} (without oxide) $= 7.13 \times 10^{-12}$ A/cm^2.

J_{oe} (no oxide + 0.4 keV H^+) $= 3.90 \times 10^{-12}$ A/cm^2.

Conclusions

A. HYDROGEN IMPLANTS ARE VERY USEFUL BECAUSE

1. CAN PASSIVATE DANGLING SI BONDS AT BULK AND SURFACE DEFECTS.
2. CAN PERMEATE DEEPLY DOWN DISLOCATIONS AND GRAIN BOUNDARIES.
3. CAN GETTER (OR PASSIVATE) FAST DIFFUSING METALLIC IMPURITIES (BUT NOT SLOW DIFFUSING IMPURITIES - AT LEAST IF DOPED FROM THE MELT).

B. HYDROGEN IMPLANTS CAN IMPROVE CELLS THROUGH IMPROVEMENT OF

1. BASE
2. SPACE CHARGE LAYER
3. EMITTER (AND EMITTER SURFACE)

C. CAUTIONS

1. HYDROGEN IMPLANTS THEMSELVES CAUSE DAMAGE.
2. HYDROGEN CAUSES BORON NEUTRALIZATION (WHICH ANNEALS OUT IF T $\geq$ 180°C OR IS NOT PRESENT IF PROCESSING TEMPERATURE $\geq$ 150°C).