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HUGHES *Research Laboratories*

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R & D STATUS REPORT

10 FEBRUARY 1982 - 9 AUGUST 1982

ARPA Order Number	4140
Customer:	Hughes Research Laboratories
Date of Contract:	9 February 1981
Amount of Contract:	$128,508
Contract Number:	N00014-81-C-0286
Principal Investigator:	R. G. Wilson 213/456-6411, Ext. 292
Contract Expiration Date:	31 December 1982
Title:	Ion Implant Damage Regrowth and Characterization, and Depth Distribution of Defects and Impurities in Proton-Implanted GaAs

<u>Program Objectives</u>

Study the effects of ion implantation damage and its annealing and associated impurity redistribution in Si and GaAs to relate these effects to GaAs ICs and VHSIC ICs. Study the depth distributions of protons and defects in proton-implanted GaAs for waveguides.

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Progress

~~We have implanted~~ Cr and O together have been implanted into damaged (amorphized) and crystalline GaAs and annealed some of the material at 830°C for 20 min. Annealed and unannealed samples have been SIMS profiled for Cr and for O. All are now being analyzed by TEM by Sadana at UC Berkeley. When the TEM results are available, the work will be reported.

The major work ~~that we wish~~ to report during this period is contained in the attached letter report to ARADCOM on the hydrogen-implanted GaAs waveguide supplement to this program. We have prepared a preliminary report of progress on this program. We are quite pleased with the progress and results of this effort, which involves implantation, SIMS, and TEM work. We should be able to prepare a paper for publication toward the end of 1982.

Publications

The manuscript entitled "Effect of oxygen on chromium-structural defects interaction in ion-implanted gallium arsenide" will appear in the September issue of Journal of Applied Physics. The other paper is still in preparation.

Man-Hours Expended During This Reporting Period

During the period from 1 February, 1982 through 31 July, 1982, 51 SMTS hours were expended on this contract. About 90% of the original technical effort has been accomplished and about 30% of the new supplement on hydrogen-implanted GaAs waveguides is completed.

Future Plans

On the original program, a few TEM measurements and a significant amount of writing remains to be done. On the new supplement, more TEM measurements and SIMS of some annealed hydrogen-implanted GaAs remain to be done.

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24 August 1982

John Zavada
DRDAR-SCF-IO
ARADCOM Bldg. 95
Dover, NJ 07801

Ref: Contract N00014-81-C-0286
"Study of depth distribution of defects and impurities in proton-implanted GaAs" phase of "Regrowth of implantation-induced damage and associated redistribution of dopants and impurities in GaAs and Si"
COTR: N. Max Yoder, ONR

Dear John:

This letter contains a progress report and preliminary results on the referenced contract, from its beginning through August, 1982.

Progress: The GaAs wafer that you furnished, designated A001, was implanted with 1.0×10^{16} cm^{-2} 300 keV ^{1}H ions at room temperature, was broken into six pieces, and each of the six pieces was annealed in nitrogen at one of the temperatures 100, 200, 300, 400, 500, or 600°C. The original plan was to leave one piece unannealed, but I inadvertently annealed all six pieces. However, we have a variety of similarly implanted GaAs that we are examining, so unannealed samples will be analyzed. Each of the six pieces was broken into three pieces. I mailed one piece of each of the six to Devendra Sadana for TEM analysis. I am holding one piece of each for possible waveguiding measurements here at Hughes Research Laboratories. I am mailing one piece of each with this letter report to you for optical and electrical analyses.

I have obtained sufficient SIMS data on ^{1}H depth distributions to say that SIMS technology is well in hand and we can determine the effects of implant temperature, fluence, energy, and annealing temperature. Some SIMS data are attached.

I include a paper on the depth distributions of damage (defects) for ^1H implanted into GaAs, and some initial verbal results from Sadana.

I include excerpts from the "Ziegler compilation" of stopping powers and ranges of ^1H ions in all materials, including Ge, which is equivalent to GaAs, to provide information on theoretical energy loss distributions to electronic and nuclear events, as you suggested. If you wish more information on this subject, I have dozens of papers on the subject, just let me know. The Anderson/Ziegler work is a summary.

I have performed SIMS measurements of ^1H depth distributions in the 13 ^1H implanted samples of GaAs and GaP that you originally provided. The results are described here and nine preliminary figures are attached that illustrate the results. These 13 samples were 0519-2, 0519-4, GaP 478 2E15 cm^{-2} at 350°C, GaP 478 2E15 cm^{-2} RT, eight A0865 samples implanted at the four temperatures -140, RT, 180, and 350°C, and each of those at the two fluences 5E14 and 5E15 cm^{-2}. The thirteenth sample was implanted at 350°C and 4.23E14 cm^{-2}. All samples were implanted with 300 keV ^1H ions.

I have also carried out an extensive study of ^1H and ^2H implants at energies from 20 to 300 keV into GaAs and Si at fluences from 1E14 to 2E17 cm^{-2} and annealed them at temperatures up to 700°C, including 350°C. This work was all done on HRL IR&D, and I include a few selected results here where they are relevant and complementary to this contract effort. In particular, I compare the results for a 350°C anneal of a room temperature implant with the results for the 350°C implants that you provided.

I am very satisfied with the progress and results so far on this mutual program and hope that you and Max Yoder feel the same. Preliminary results are summarized below.

Preliminary Results: Sadana sees no evidence of defects or measurable damage in any unannealed implanted samples of GaAs by TEM measurements, in agreement with the recently published results of Snyman and Neething (copy attached). Snyman and Neething give damage depth distributions for ^1H implants into GaAs measured by passing alpha particles through air and foils. We will eventually compare these profiles with annealed redistributed ^1H profiles of ^1H implants.

I measured the approximate densities of Si in your GaAs (Si) samples and the S density in your GaP(S) samples. The results are: GaP(S) $\sim 1.8 \times 10^{18}$ cm^{-3}, GaP(Si) $\sim 1 \times 10^{15}$ cm^{-3}, 0519 GaAs(Si) RT $\sim 6 \times 10^{18}$ cm^{-3}, A0865P RT $\sim 8 \times 10^{17}$ cm^{-3}, A0865P2 RT $\sim 6 \times 10^{17}$ cm^{-3}. Unfortunately, I did not learn until later depth measurements were made, that we did not profile quite deeply enough to determine for certain whether any redistribution of S (or Si) occurred in the deep regions of the ^1H implants. I will repeat these measurements to a greater depth to answer this question.

Comparison of the 350°C implants with no post anneal with room temperature implants subsequently annealed at 350°C (IR&D) show essentially the same redistributed ^1H profiles. That is, a 350°C implant with no anneal and a room temperature implant annealed at 350°C have the same ^1H depth distribution and both are clearly redistributed from an unannealed room temperature implant. See the attached preliminary figures.

The SIMS detection sensitivities (background subtracted) for ^1H in GaAs and GaP are between 10^{17} and 10^{18} cm^{-3}.

^1H profiles are slightly narrower in GaP than in GaAs, as might be expected because the average Z of GaP is less than that of GaAs. Profiles of ^1H in both GaAs and GaP are wider than in the lower Z substrate Si (IR&D).

300 keV ^1H ranges in GaP are 1+% greater (reproducibly) than in GaAs. Note: There is an extra peak at shallow depth in the ^1H depth distribution for the 0519 samples that you provided. This peak probably results from the implantation of an incorrect ^1H ion energy that is implanted along with the desired 300 keV energy. Also, the implant energy for the 0519 samples appears to be $\sim$ 2% less than 300 keV as determined by comparison with our 300 keV ^1H implants and with those of the A0865 series (NRL). This incorrect energy probably results from dissociation in the vicinity of the mass separator when the beam line pressure is too high. Its intensity is only about 1% of the correct energy, but it is measurable.

Diffusion of H atoms during implantation at 180 or 350°C is seen in the appropriate figures. Detailed depth distributions depend on the implantation fluence and energy and on the associated different H densities.

The 350°C ^1H implant profiles show a broadening of the peak toward the GaAs surface at high H density and a diffusion to deeper depths for H densities below $\sim 10^{18}$ cm^{-3}, as we have also seen for S, Se, and Te in GaAs. The implanted ^1H atoms diffuse to $\sim$ 8 μm with a density of $\sim 10^{18}$ cm^{-3}. These results probably explain (or are at least significant) the electrical or wave guiding results of Hunsperger for deep wave guiding in annealed GaAs.

The 180°C implants show a slight redistribution in the directions of the 350°C implants.

All of these observations are less evident for the 5×10^{14} cm^{-2} fluences because of the reduced detection (dynamic range) of the SIMS measurements, and possibly because of the lower defect/damage level.

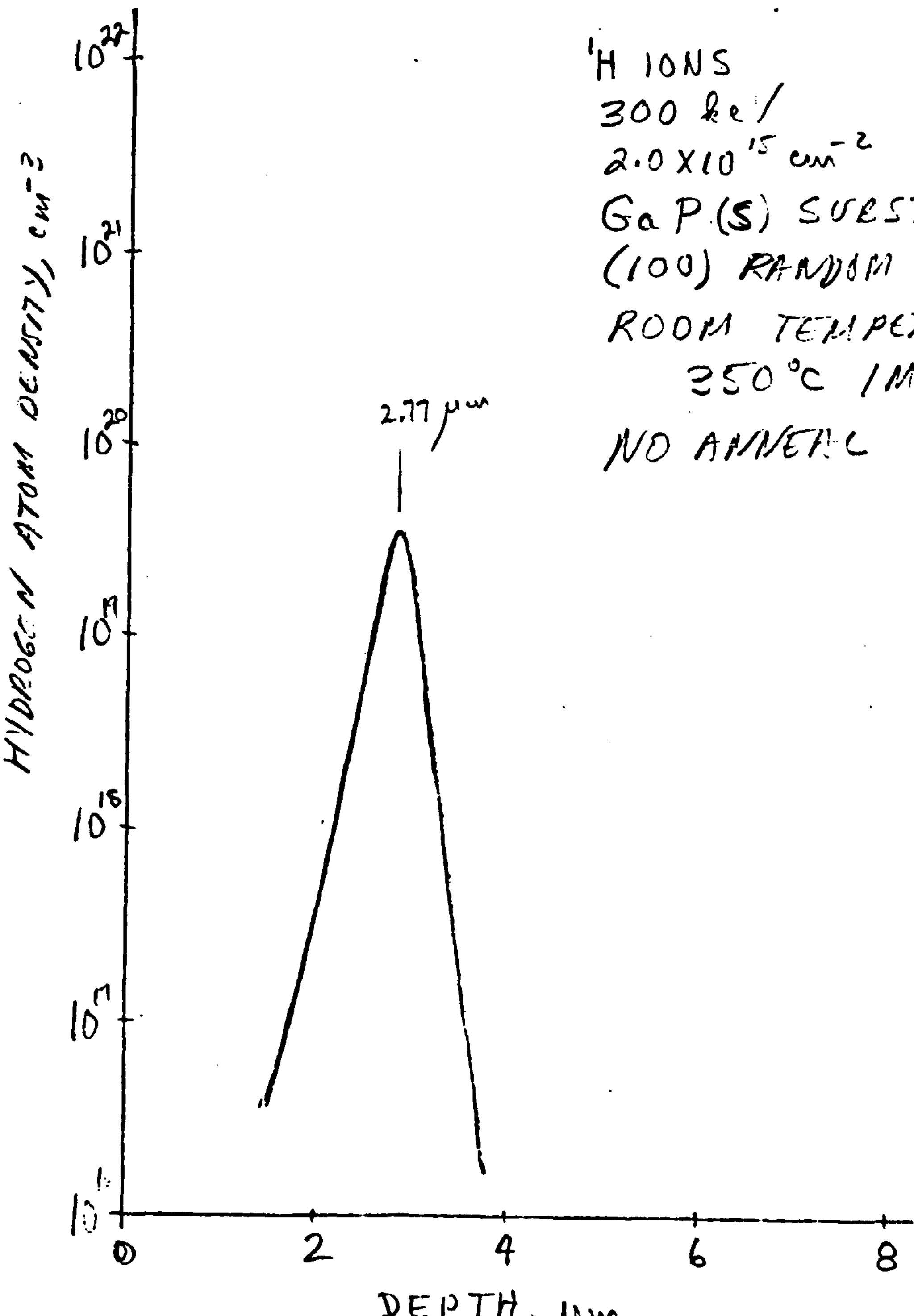
Sincerely,

R. G. Wilson, Head
Beam Processing Section
Electron Device Physics Dept.

Encl:

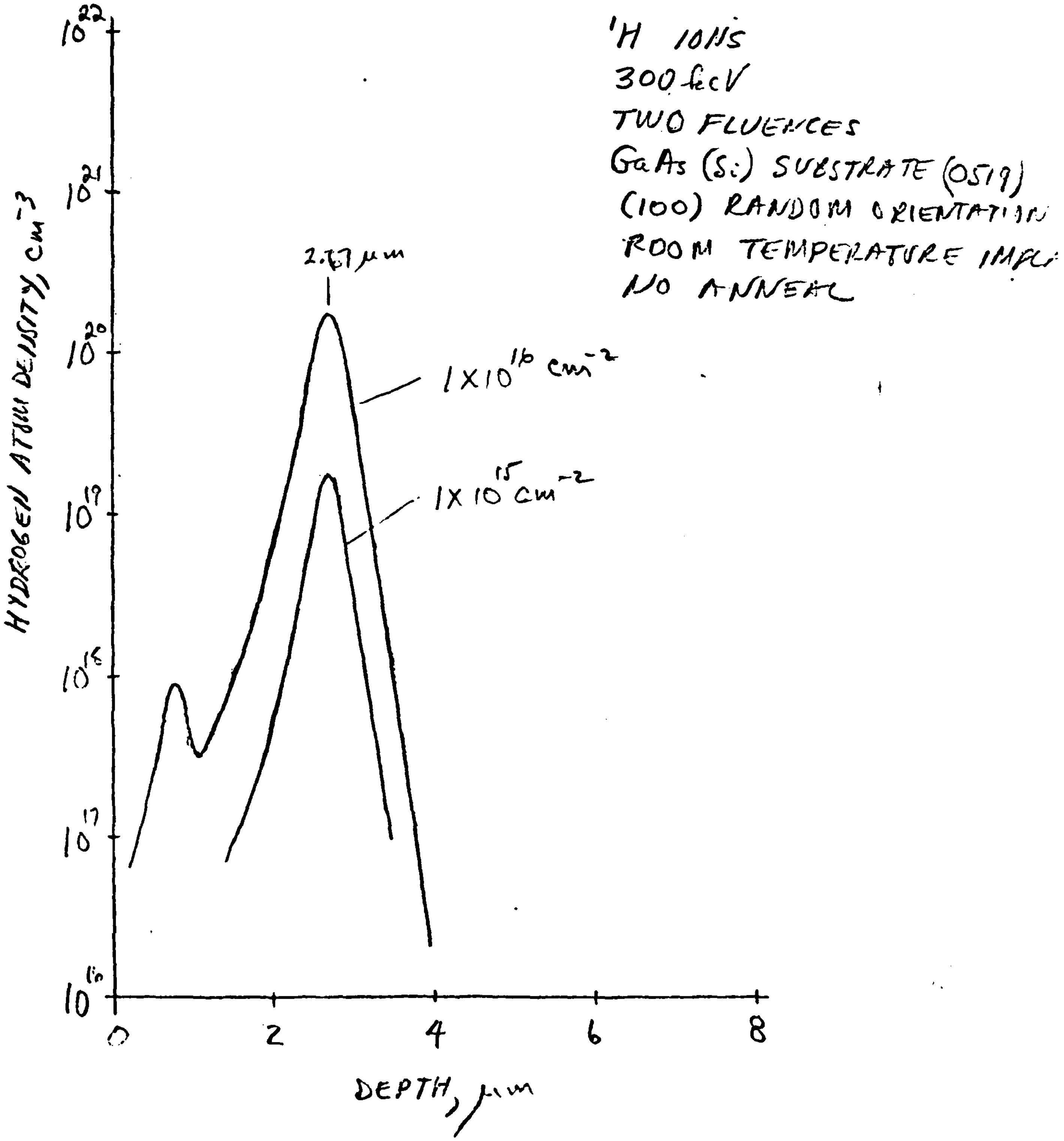
/dlm

(GaP 478 (2AV)) 2

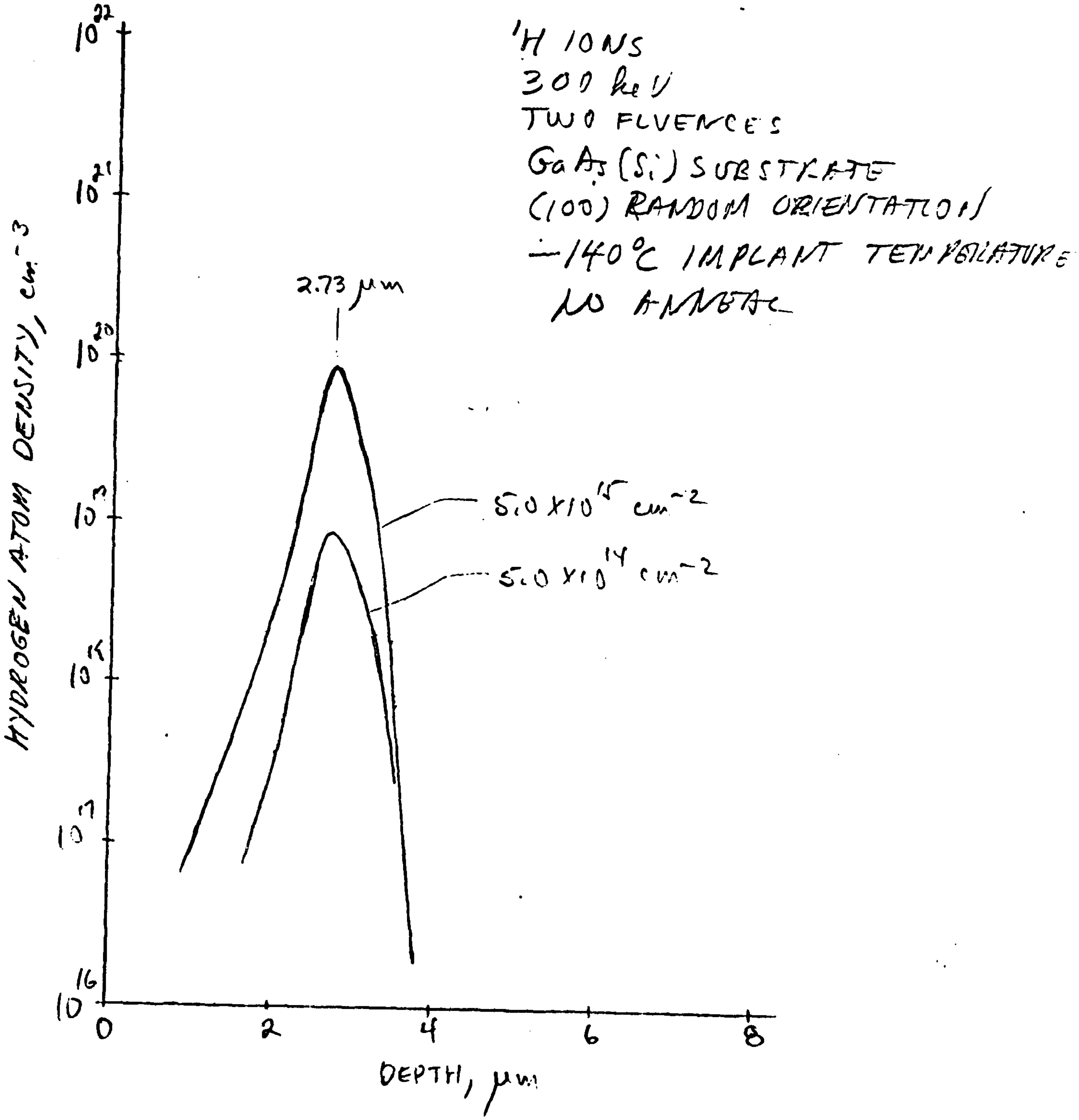


^{1}H IONS
300 keV
2.0×10^{15} cm^{-2}
GaP (S) SUBSTRATE
(100) RANDOM ORIENTATION
ROOM TEMPERATURE AND
350°C IMPLANTS ARE SAME
NO ANNEAL

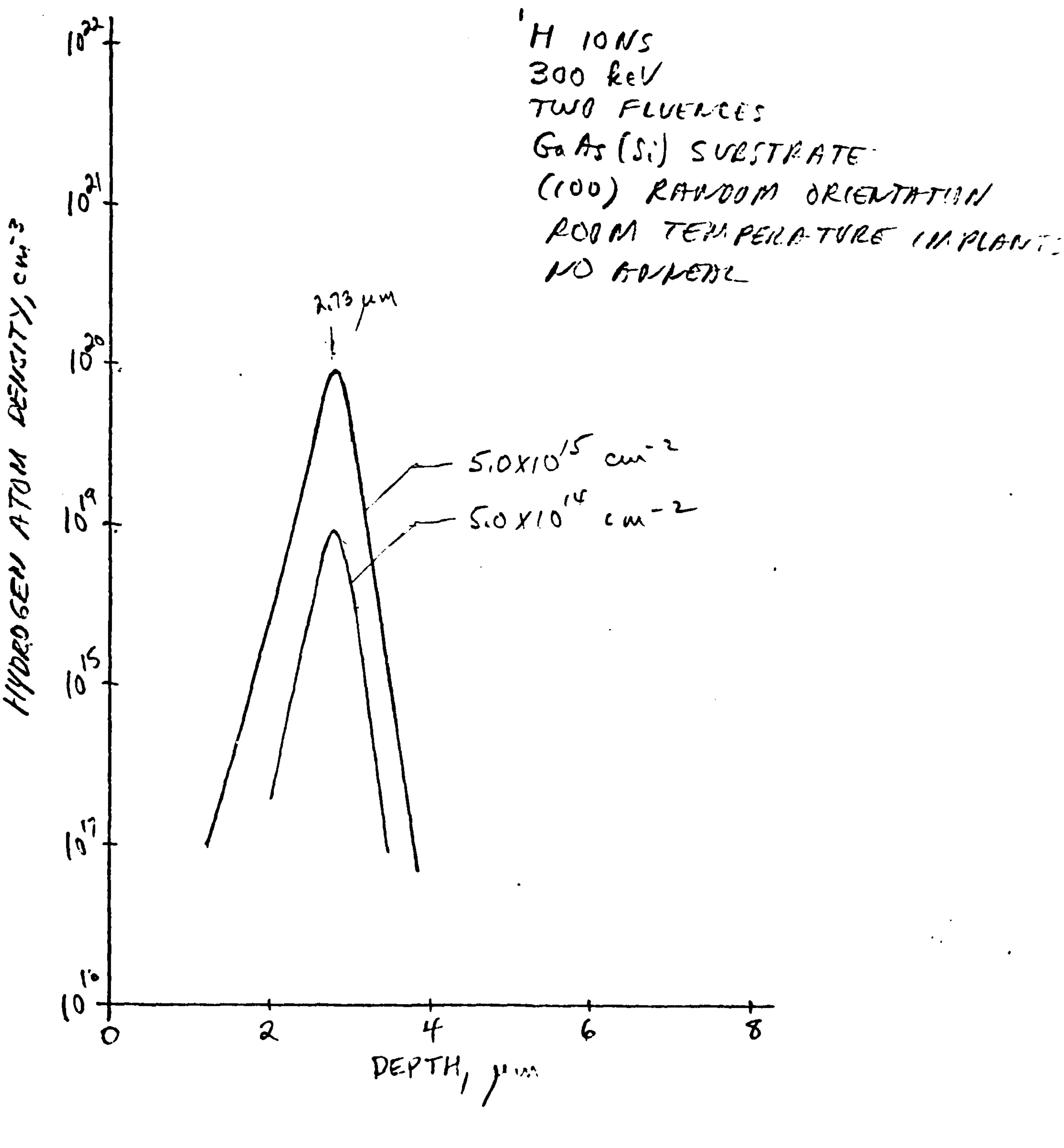
(0519 = 2/4 a1 GaAs, (2 A'J))



A0765 -140 (ZAV)

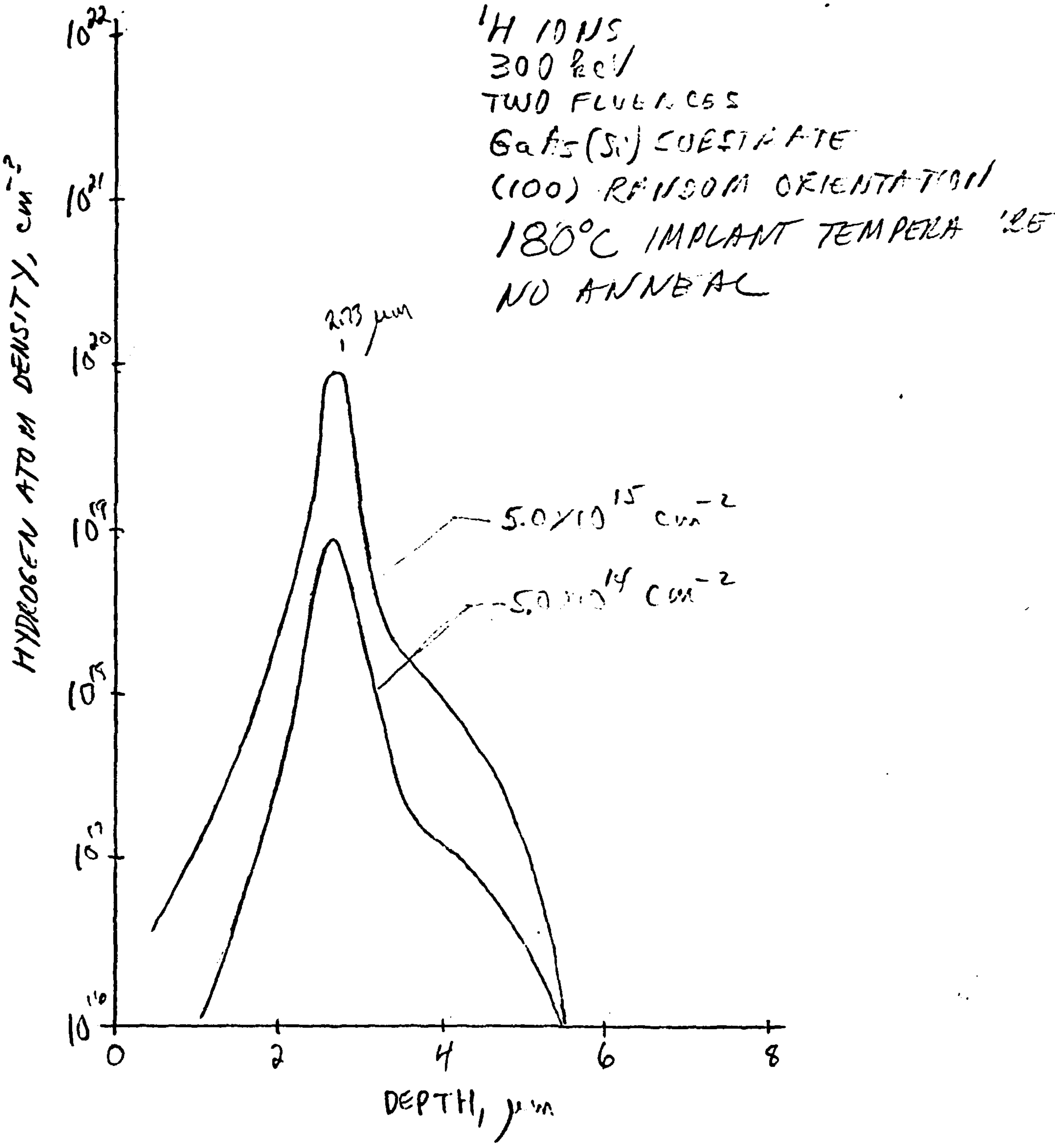


A0865 RT (ZAU)

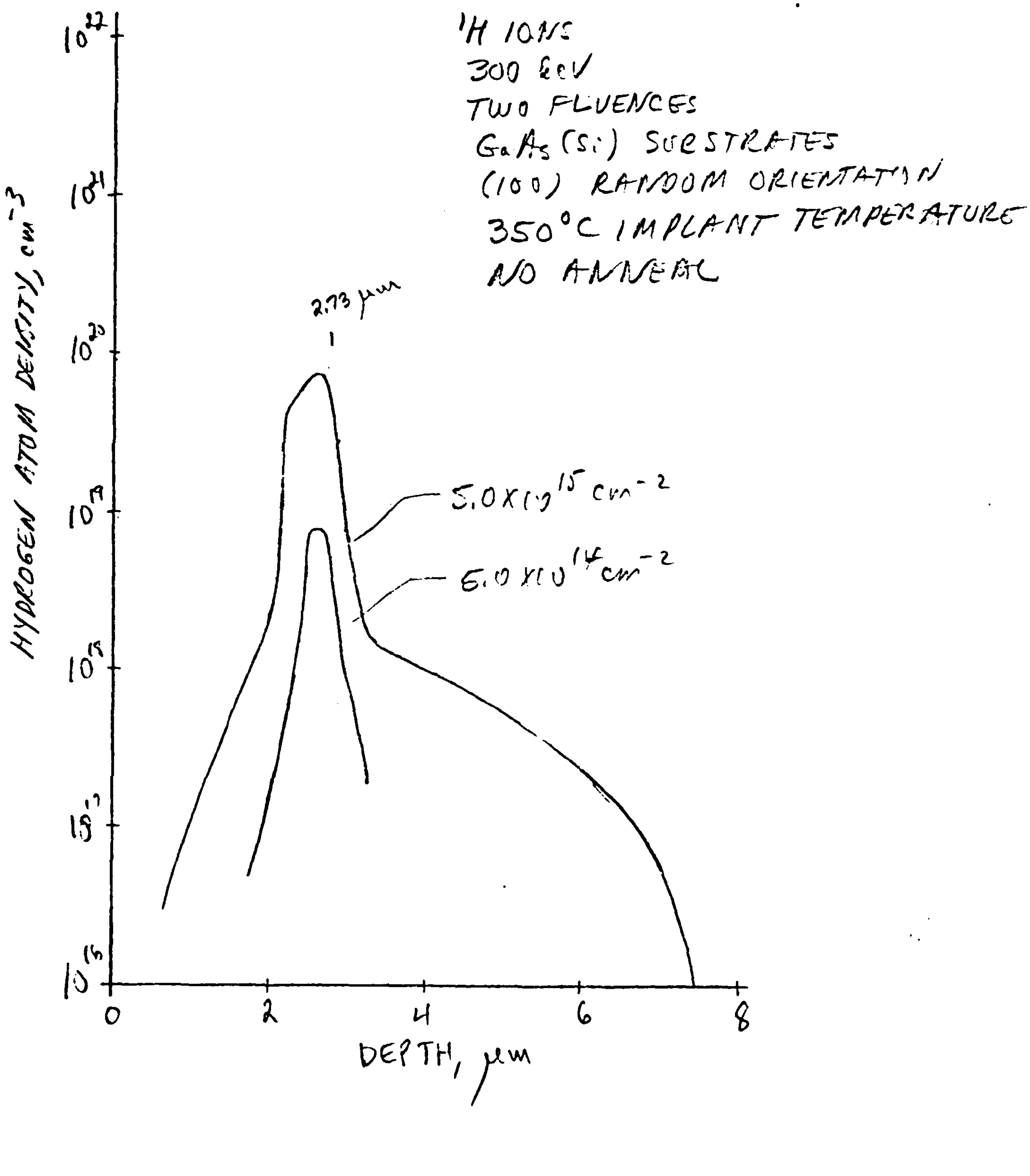


^{1}H IONS
300 keV
TWO FLUENCES
GaAs (Si) SUBSTRATE
(100) RANDOM ORIENTATION
ROOM TEMPERATURE IMPLANT;
NO ANNEAL
2.73 μm
5.0×10^{15} cm^{-2}
5.0×10^{14} cm^{-2}
HYDROGEN ATOM DENSITY, cm^{-3}
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
0
2
4
6
8
DEPTH, μm

A0805 180°C (ZAU)

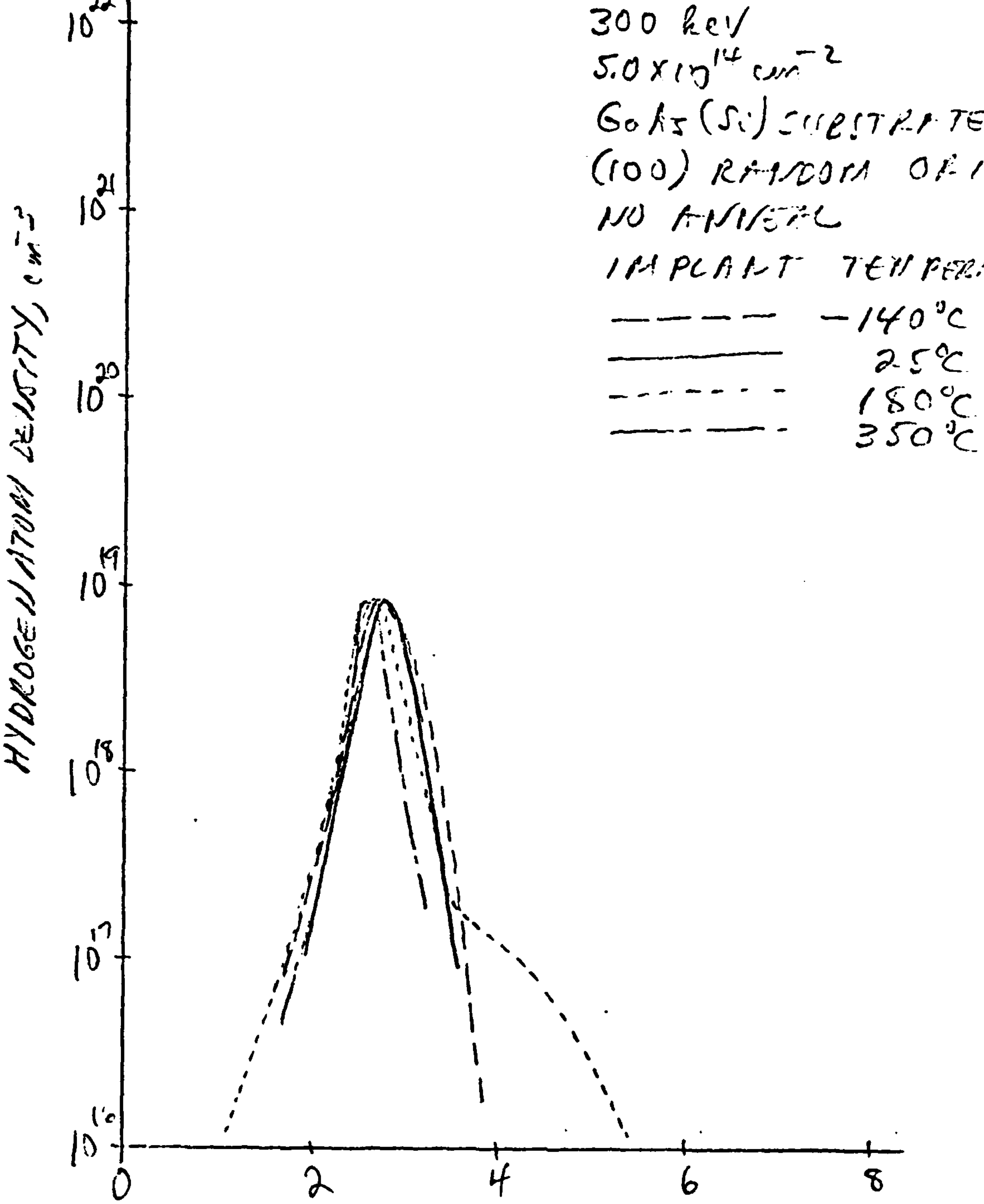


A0865 350°C (ZAU)

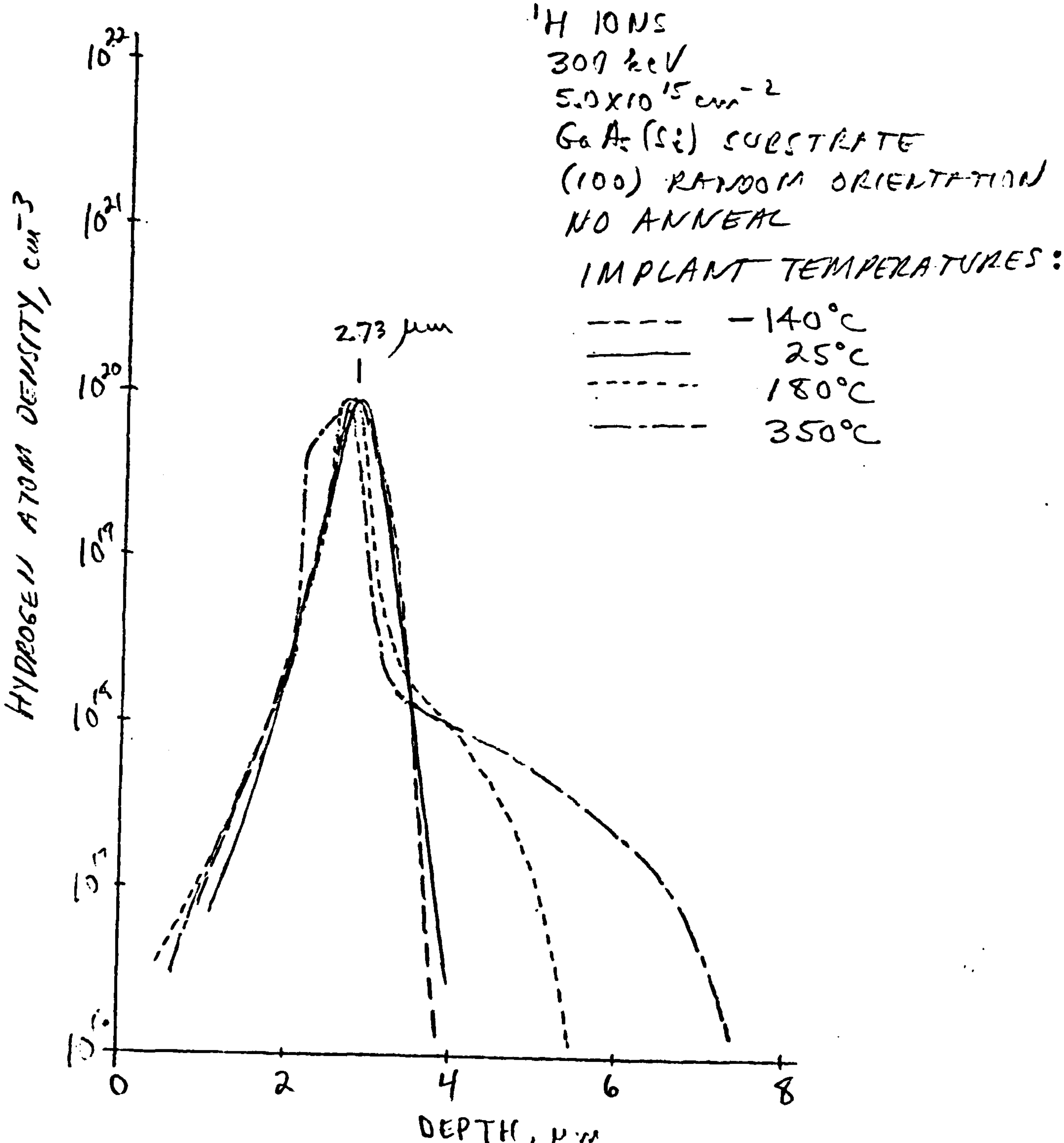


A0865 T_I's (ZAU)

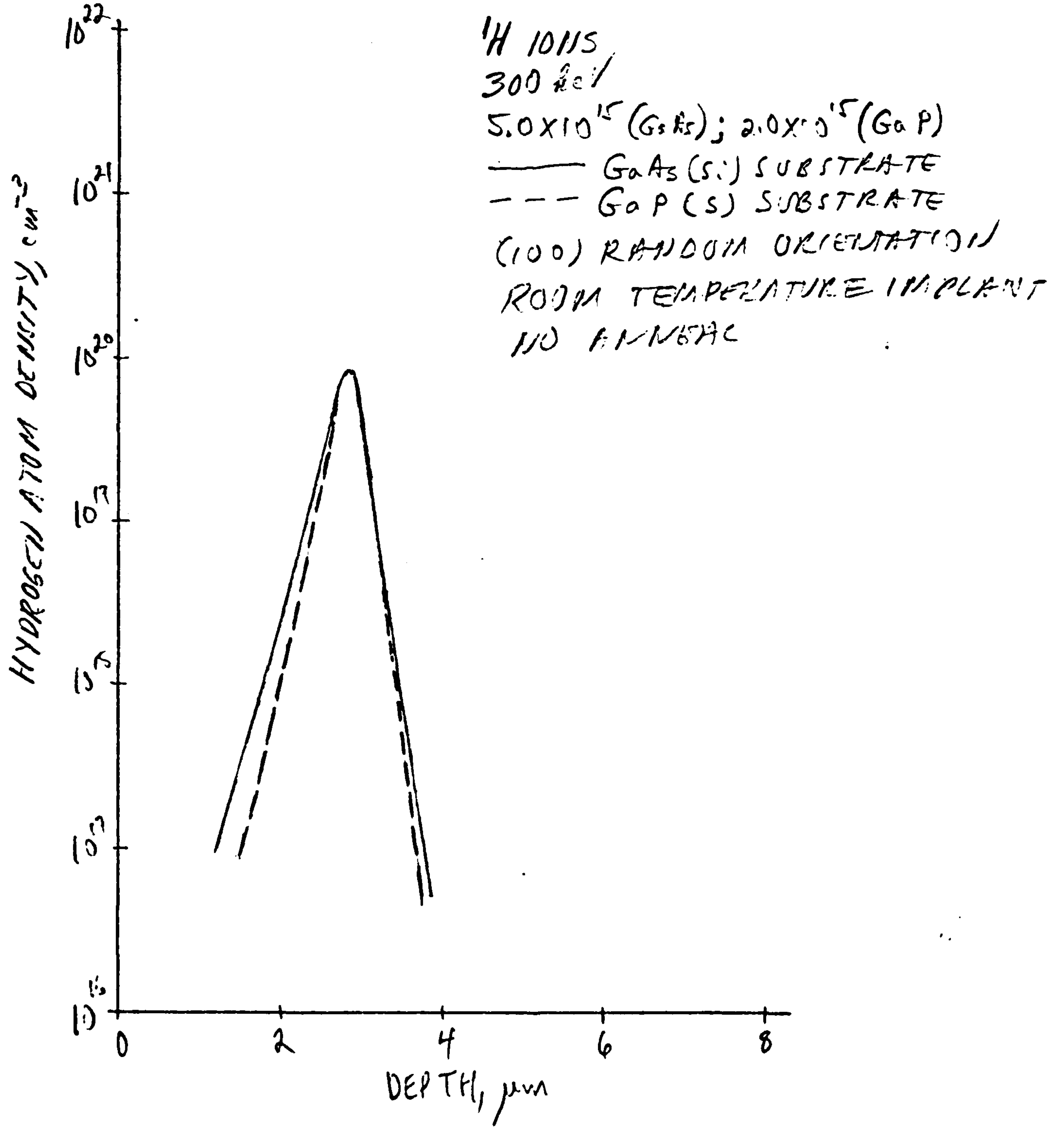
^1H IONS
300 keV
5.0×10^{14} cm^{-2}
GaAs (Si) SUBSTRATE
(100) RANDOM ORIENTATION
NO ANNEAL
IMPLANT TEMPERATURES:



A0865 T_I's (2MV)



GaAs & GaP (ZAV)



1H IONS
300 keV
5.0X10^15 (GaAs); 2.0X10^15 (GaP)
GaAs (Si) SUBSTRATE
GaP (S) SUBSTRATE
(100) RANDOM ORIENTATION
ROOM TEMPERATURE IMPLANT
NO ANNEAL
HYDROGEN ATOM DENSITY, cm^-3
DEPTH, µm
0
2
4
6
8

H1599/1600

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