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R & D STATUS REPORT

10 AUGUST 1981 - 9 FEBRUARY 1982

ARPA Order Number	4140
Customer:	Hughes Research Laboratories
Date of Contract:	9 February 1981
Amount of Contract:	$108,914.
Contract Number:	N00014-81-C-0286
Principal Investigator:	R. G. Wilson 213/456-6411, Ext. 292
Contract Expiration Date:	30 June 1982
Title:	Ion Implant Damage Regrowth and Characterization

Program Objective

Study the effects of ion implantation damage and its annealing and associated impurity redistribution in Si and GaAs and to relate these effects to GaAs ICs and VHSIC ICs.

10 to the 15th power / sq cm

Summary

Three cross section transmission electron microscope (XTEM) micrographs show the development of crystal damage as a function of implantation fluence for 300 keV silver (Ag) implanted into Si. A fourth XTEM micrograph shows the depth distribution of defects for the 10^{15} cm^{-2} fluence annealed at 800°C that shows a buried defect layer and a surface damage layer. The depth distribution of Ag atoms measured by secondary ion mass spectrometry (SIMS) shows that the Ag atoms are located in these same two regions, demonstrating that the residual Ag atoms are complexed with the defect structure in annealed implanted Si.

10 to the 14th power / sq cm

The XTEM micrograph for the 10^{14} cm^{-2} implant fluence shows a buried "amorphous" region with what appears to be a high density of microcrystallites within the "amorphous" layer. This structure is very interesting and we wish to study the origin and change within this layer with further annealing of these microcrystallites. These results favor the formation of an amorphous layer as the result of the overlapping of individual damage clusters, rather than from the accumulation of a critical density of point defects before crystalline Si transforms into the amorphous state.

The SIMS profiles given in Figure 8878-209 of the last report are interpreted in light of the XTEM results. All observations except one are consistent with the proposed model. The one discrepancy deserves further study.

Two sets of samples were implanted with Cr into Si held at 250°C during implantation and one set of wafers was implanted with oxygen at 10^{16} cm^{-2} into (100) and (111) Si for annealing studies using RBS and XTEM.

Progress on two publications is described.

Problem Areas

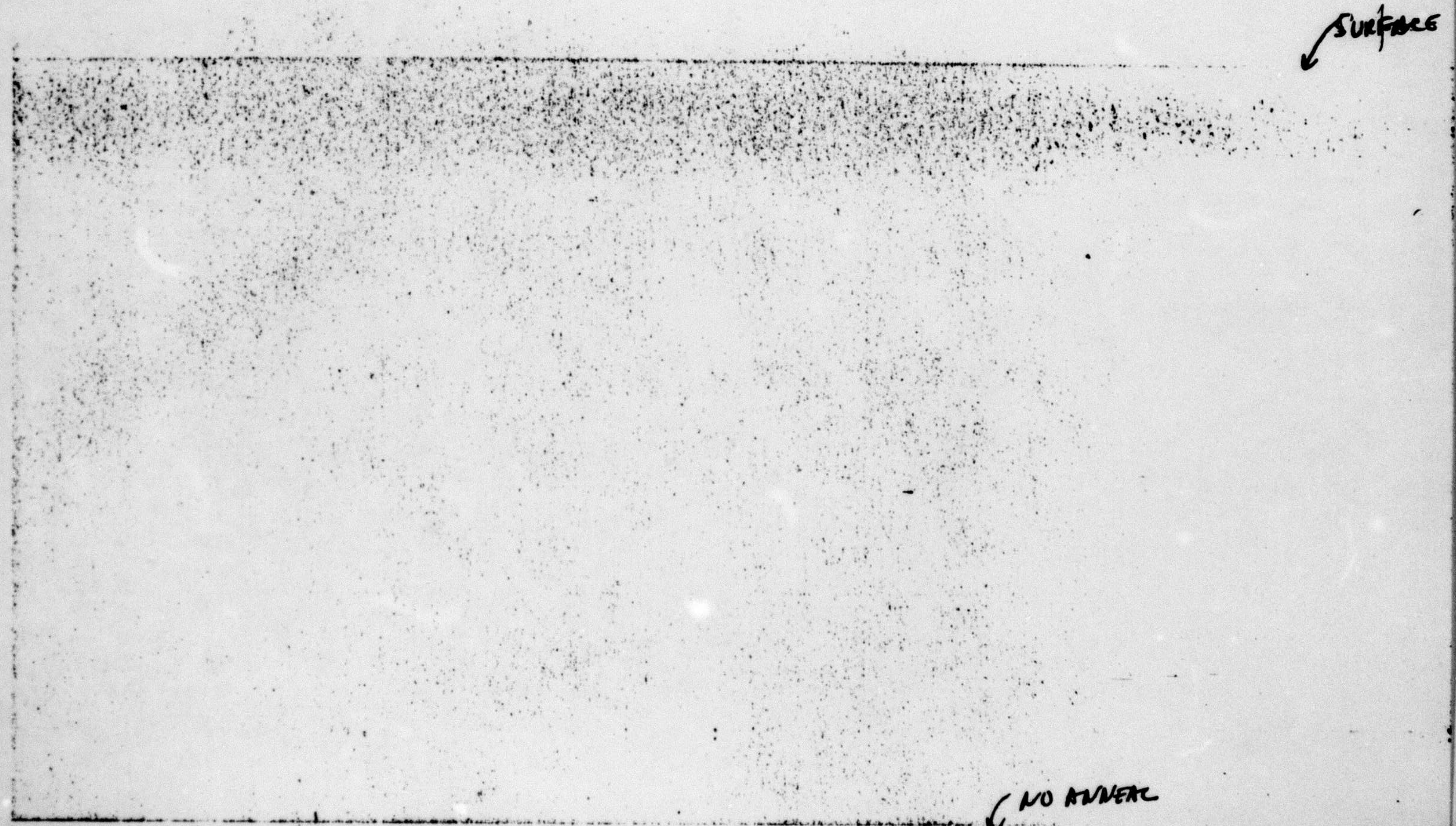
A great deal of time is being required to get RBS and XTEM samples prepared and measurements made on busy equipment. Therefore results are slow in coming. Funds remain for both RBS and XTEM efforts and a no cost time extension to 30 June 1982 has helped, but will probably not allow us to complete all of the planned work, interpretations, and publications. A possible additional time extension to 30 December 1982 is anticipated to allow another task to be added and that time would also be helpful for completing more satisfactorily the planned work.

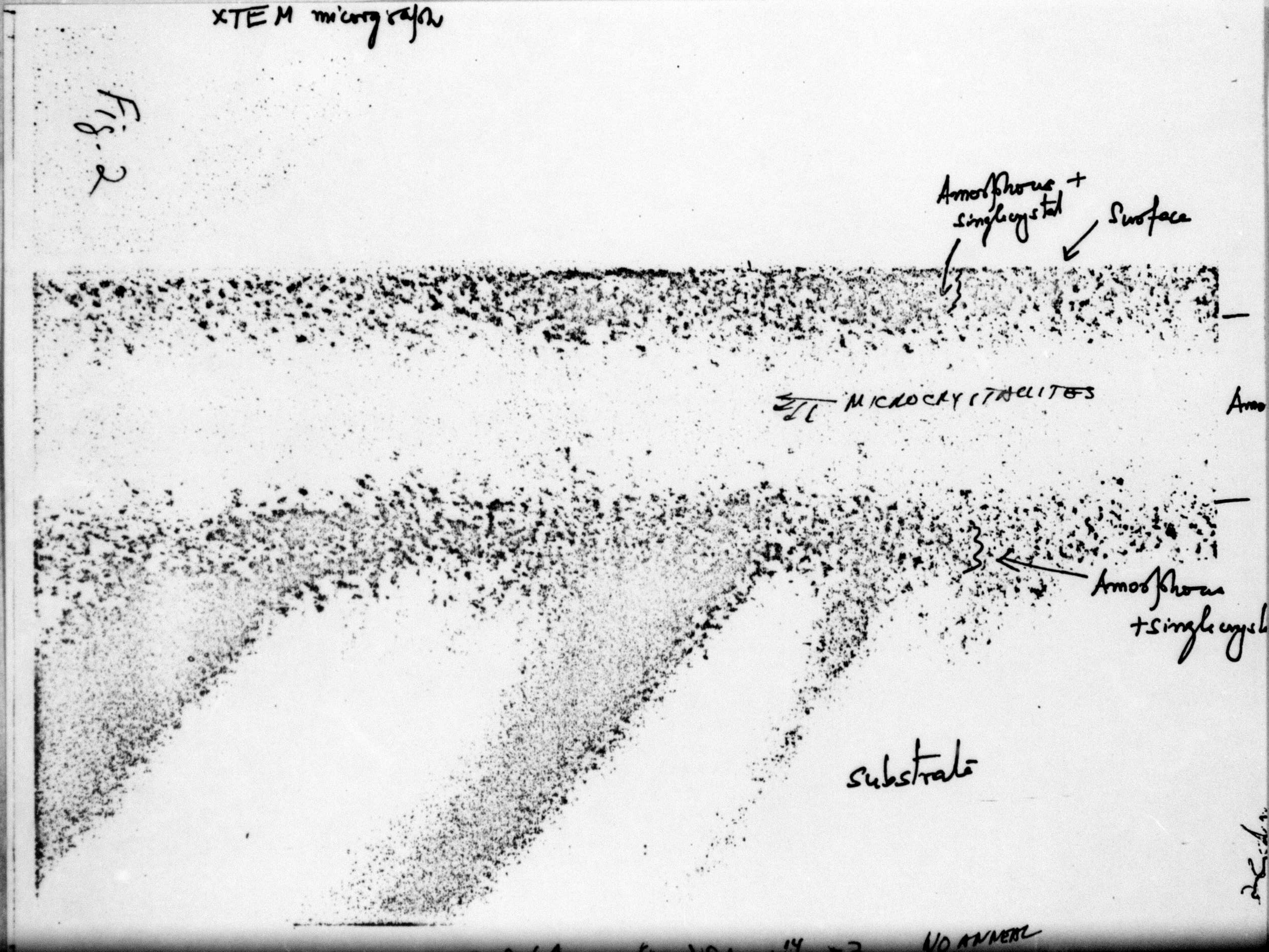
XTEM Results

Figures 1 through 3 show XTEM micrographs for 300 keV Ag implanted in (100) Si before annealing. Figure 1 is for a fluence of 3×10^{13} cm^{-2}; Figure 2 is for 10^{14} cm^{-2}; and Figure 3 is for 10^{15} cm^{-2}. The data for 3×10^{13} cm^{-2} (Fig. 1) show a damaged but not amorphous graded layer as would be expected for a low fluence implant. The data for 10^{14} cm^{-2} are discussed in the next section. The data for 10^{15} cm^{-2} (Fig. 3) show a broad amorphous layer extending from the surface to a substantial depth.

The XTEM micrograph of Fig. 4 is for a 300 keV, 10^{15} cm^{-2} Ag implant into Si and annealed at 800°C. This micrograph corresponds directly to the SIMS profile of Ag shown in Fig. 7 (8878-152R1) of the last report. The XTEM micrograph shows a buried layer of damage at $\sim$ 0.25 μm and a heavy concentration of defects near the surface. The corresponding SIMS data show Ag atoms at these same two locations.

Fig. 1




XTEM micrograph
Amorphous +
single crystal
Surface
MICROCRYSTALLITES
Amorphous
+single crys
Substrate
NO ANNEAL
Fig. 2

300 keV Ag → (111) Si · 10^{15} cm^{-2}
NO ANNEAL

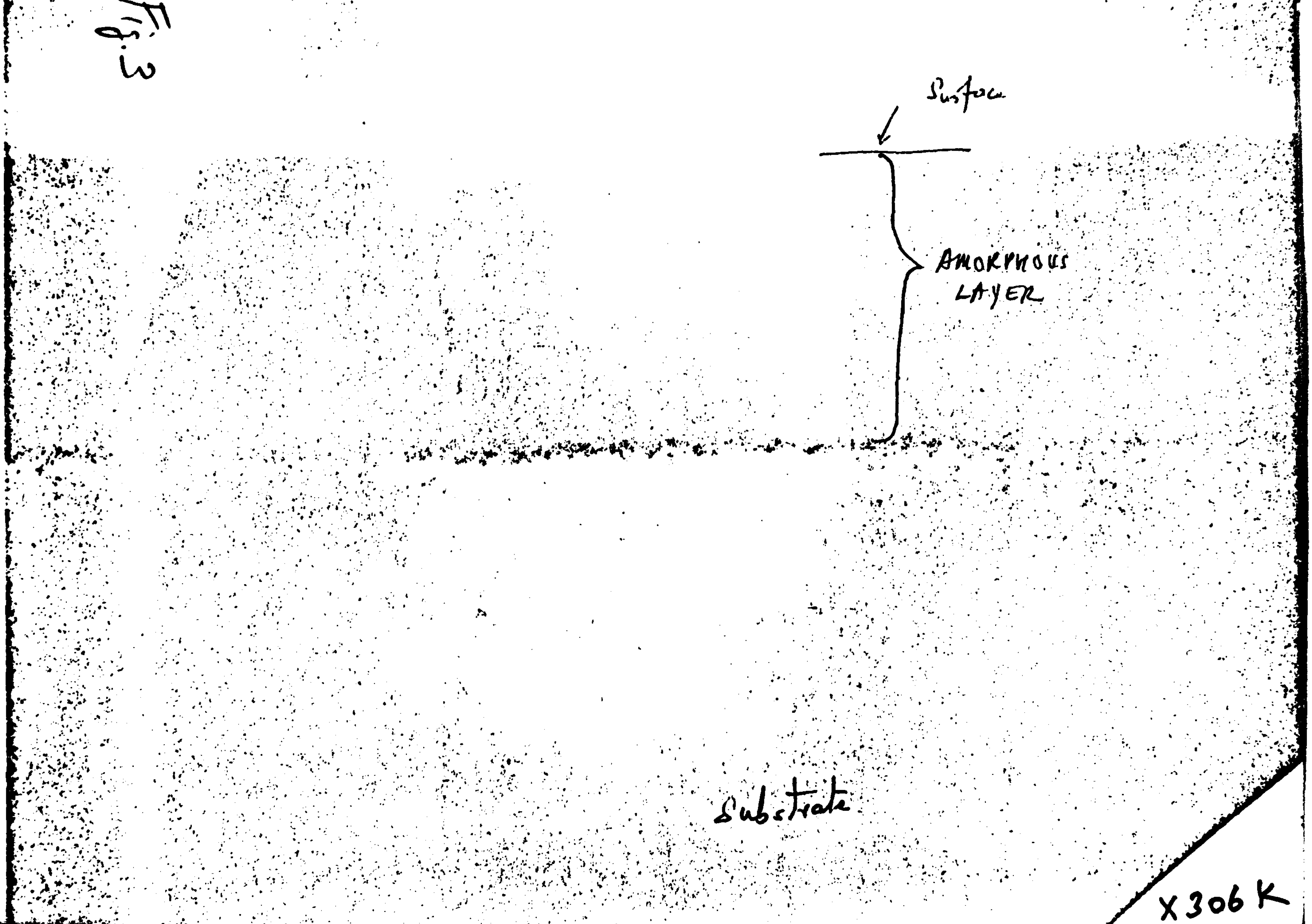


Fig. 3

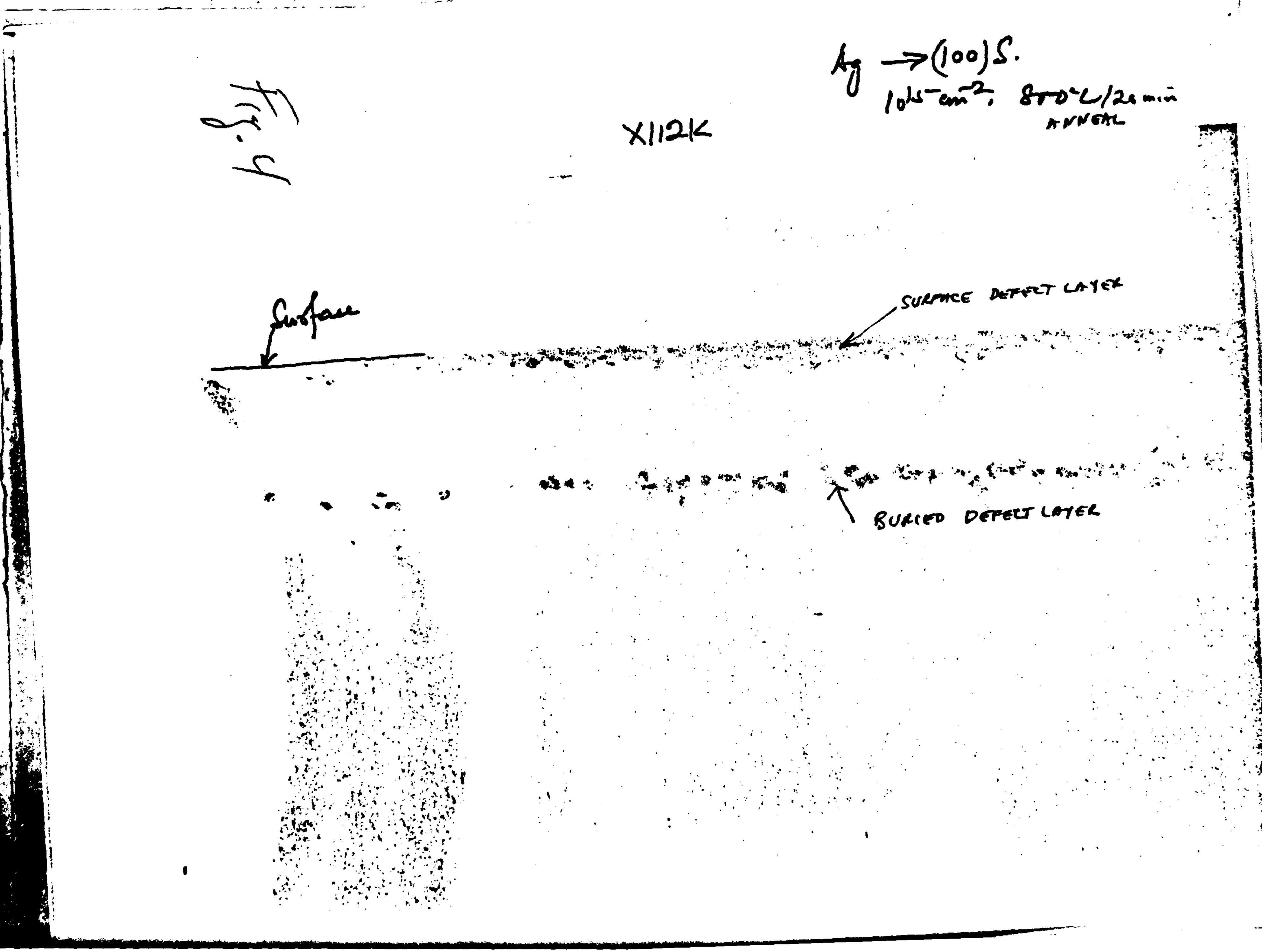

Ag → (100) Si
10^15 cm^-2, 850°C/20 min
ANNEAL
X112K
Surface
SURFACE DEFECT LAYER
BURIED DEFECT LAYER

Fig. 4

Discussion of the 10^{14} cm^{-2} Buried Amorphous Layer

Implant: 1.0 x 10^{14} cm^{-2}, 300 keV Ag, (100) Si, No Anneal. Resulting Structure: a buried amorphous layer. XTEM Results and Interpretation: The damage structure observed by XTEM for these conditions is complex and interesting. The XTEM micrograph shown in Figure 2 has structure within the buried amorphous layer region that we believe comprises microcrystallites; however, this conclusion needs to be confirmed by further experiments. The observation of such structure within the buried amorphous layer raises important questions: How does the crystalline Si transform into amorphous Si? What are the critical parameters? For example, does the amorphous layer form as a result of the overlapping of individual damage clusters (small amorphous regions), or is there a critical density of point defects that is required before crystalline Si transforms into the amorphous state? The micrograph of Figure 2 tends to support the first possibility, however further work is clearly needed to answer these questions definitively. The next experiment that we wish to perform in this direction is to study the growth of the amorphous Si and the microcrystallites within the amorphous region at a selected area. We will determine whether the crystallites increase or decrease in size and what happens to the roughness of the amorphous/crystalline Si interfaces (as a function of annealing temperature).

Interpretation of the SIMS profiles of Fig. 8878-209 given in the last report and shown here as Figs. 5 and 6.

Implants: various fluences at 300 keV, (100) Si, annealed at 550°C for 20 min

Interpretation based on XTEM measurements of the depth distributions of defects:

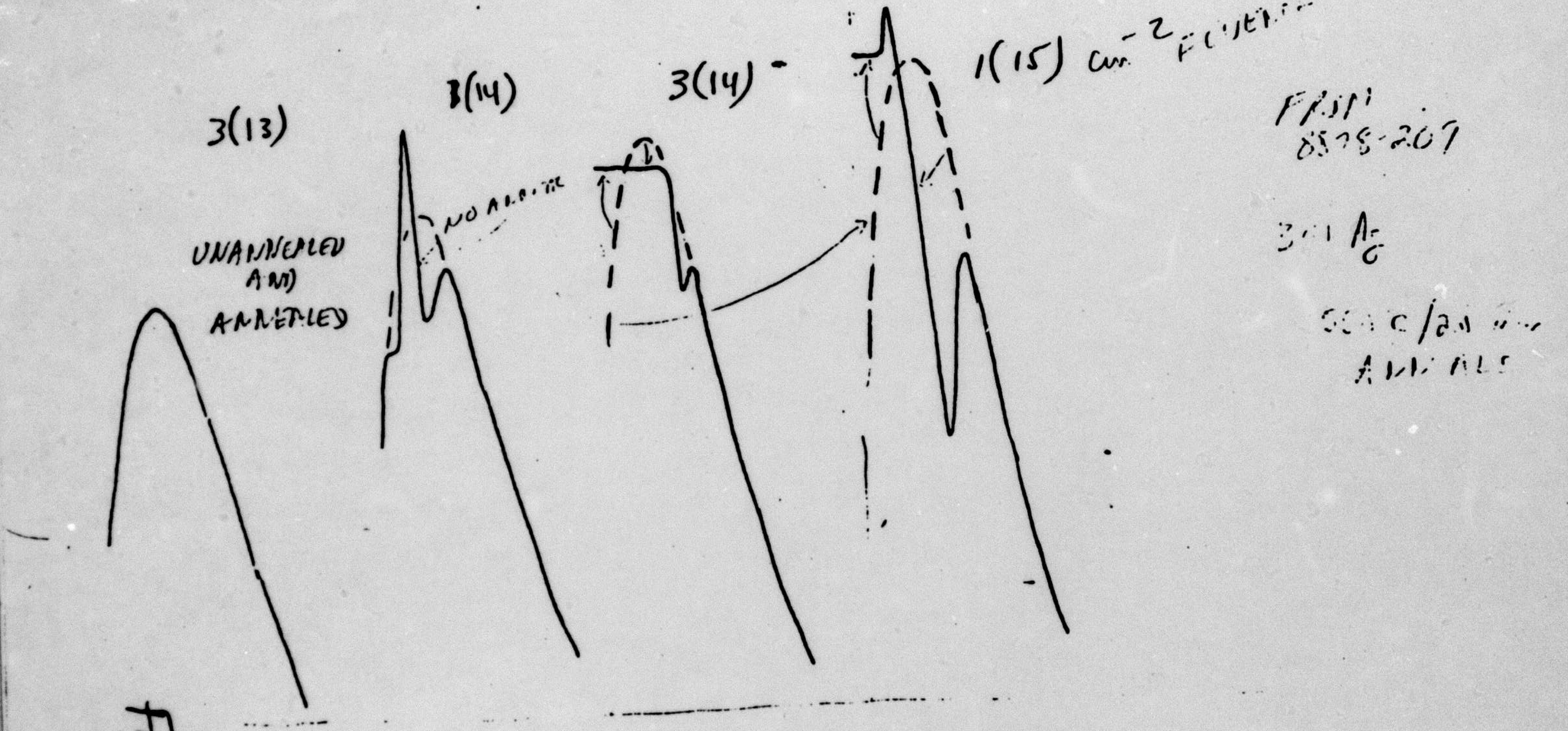


Figure 5.

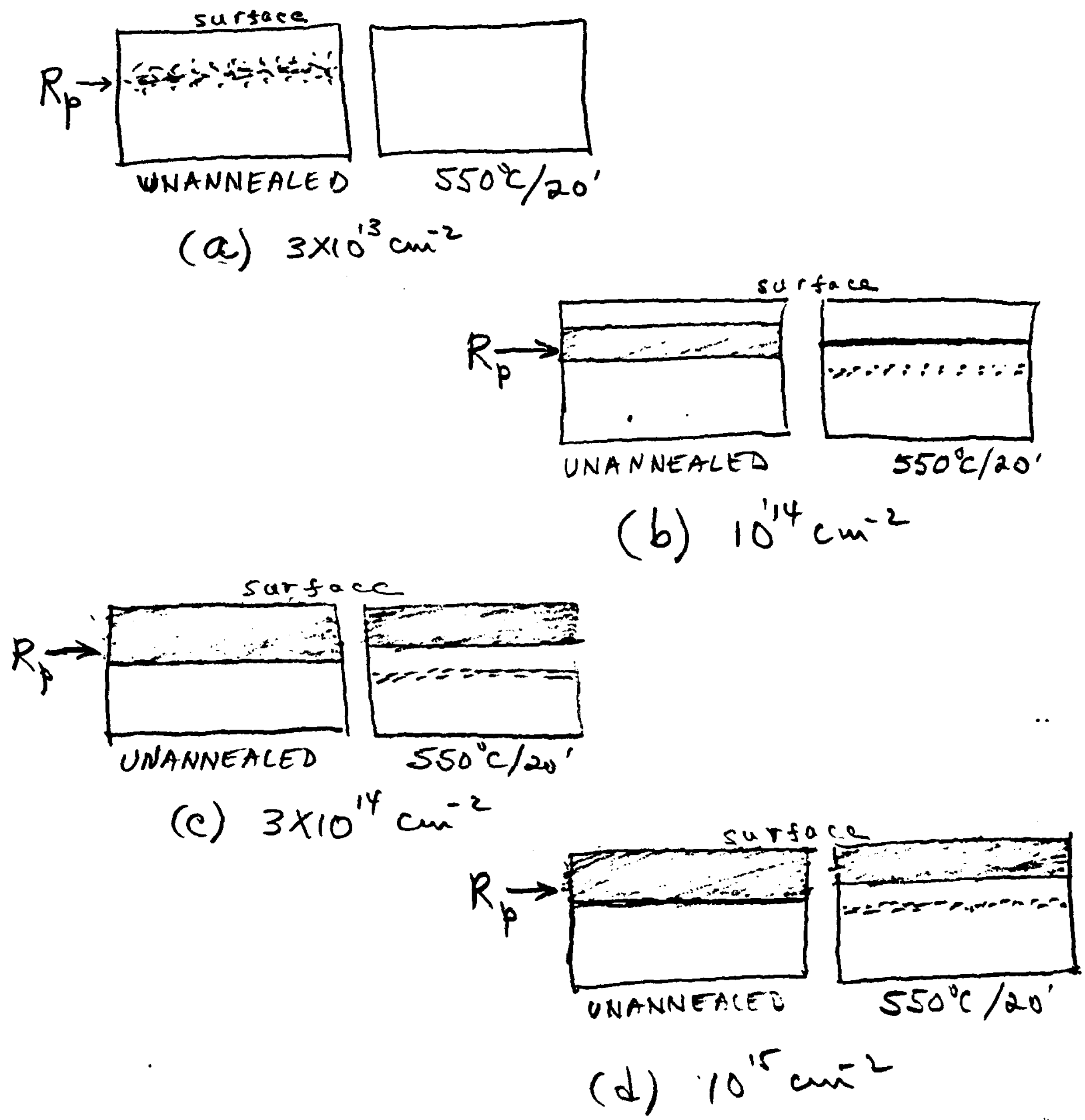


Figure 6. Schematic of the XTEM micrographs interpretation.

3×10^{13} cm^{-2} fluence:

The dose in this case was probably too small to create a buried amorphous region. Rather, it created isolated damage clusters (Figure 6a) in the vicinity of R_p. These clusters annealed out at the 550°C annealing temperature. Consequently, Ag did not see any discrete defect-rich regions where it could segregate. Diffusion was also minimized because of the low annealing temperature used.

1×10^{14} cm^{-2} fluence:

Here the dose used was probably high enough to cause the formation of a buried amorphous layer. Subsequent annealing of this type of structure produces two discrete layers of damage as already observed (see the attached article by Sadana et al.) and is shown schematically in Figure 6b. The shoulder near the surface in the Ag profile is believed to correspond to the vacancy-rich region and the two peaks occur in the vicinity of the two damage layers.

3×10^{14} cm^{-2} fluence:

The dose of Ag used here probably produced a continuous amorphous layer that extends to the surface of the sample (Figure 6c). In this type of damage configuration there is only one amorphous/crystalline interface available for regrowth. Comparing the regrowth rate results from this sample with that of the 10^{14} cm^{-2} sample at the deeper interface indicates that the regrowth is retarded in the 3×10^{14} cm^{-2} sample. The flat region of the profile represents the width of the amorphous layer. A small peak in the deeper region is typical of most implantation and probably correspond to a narrow layer of damage clusters at this depth.

1×10^{15} cm^{-2} fluence:

In this case also, the initial damage structure is a continuous amorphous layer extending to the surface (this particular sample has already been studied in the TEM). In principle, the explanation of regrowth of the amorphous layer for the 3×10^{14} cm^{-2} sample should also hold here, but apparently there is a contradiction, in that the growth rate of amorphous Si in the 10^{15} cm^{-2} sample is accelerated as compared with the 3×10^{14} cm^{-2} sample. The first peak correspond to the amorphous/crystalline interface and the second peak occurs at a damage cluster-rich region as already seen in the TEM measurements.

In conclusion, the 550°C annealing results can be explained by considering a layer of isolated damage clusters, a buried amorphous layer, and a continuous amorphous layer, and by predicting their annealing behavior based on the experience with other ions. However, the results of 3×10^{14} cm^{-2} and 10^{15} cm^{-2} samples are in disagreement and need further exploration. At higher annealing temperatures, Ag will diffuse into the bulk because of its low solubility in Si. Fairly high concentrations of Ag at 700 and 800°C indicate the formation of some kind of Ag precipitates that seem to break up at 900°C. The reason for the movement of the deeper peak toward the surface is not yet clear.

Regarding Cr, we hesitate to propose any explanation yet, because it is so complex. However, combining the SIMS results with the TEM studies could prove very useful to understand regrowth of Amorphous Si on single crystal Si.

Samples implanted for XTEM or RBS

Two sets of samples have been implanted and submitted for XTEM or RBS analysis, but the measurements or results are not yet completed. Si samples held at 250°C during implantation were implanted with 300 keV Cr at 10^{13}, 10^{14}, and 10^{15} cm^{-2} for both XTEM and RBS measurements. Sample of (100) and (111) Si were implanted with 300 keV oxygen at 10^{16} cm^{-2} for RBS studies as a function of annealing temperature.

Publications

The manuscript of the paper titled "Effect of oxygen on chromium-structural defects interaction in ion-implanted gallium arsenide" by Sadana, Washburn, Zee, and Wilson has been revised and submitted to the Journal of Applied Physics. We hope for a publication data assignment soon. A paper showing the agreement among SIMS, XTEM, and RBS measurements for the Ag atom depth distributions and depth distributions of defects and damage is still in preparation.

Man-Hours Expended During this Reporting Period

During the period from 1 August 1981 to 31 January 1982, 233 hours were charged to this contract (70 SMTS hours, 0 MTS hours, and 163 TE hours). We estimate that 85% of the technical effort has been accomplished as a result of the work done through 31 January 1982.

Future Plans

More RBS and XTEM measurements will be made. Some interpretation of data will be done and work will continue on publications.

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