Title

APPLICATIONS OF HEAVY-ION RUTHERFORD BACKSCATTERING SPECTROMETRY (HIRBS) TO THE ANALYSIS OF CONTACT STRUCTURES ON GaAs AND Ge

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APPLICATIONS OF HEAVY-ION RUTHERFORD BACKSCATTERING SPECTROMETRY (HIRBS) TO THE ANALYSIS OF CONTACT STRUCTURES ON GaAs AND Ge

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Abstract

The use of Heavy-Ion Rutherford Backscattering Spectrometry (HIRBS) for the analysis of layered structures on GaAs and Ge substrates has been studied. Direct comparisons of data obtained using both ^{16}O and ^{4}He projectiles for the characterization of contact structures have demonstrated the advantages of HIRBS for the study of substrates with increased atomic masses due to the improved mass resolution of the method for high Z materials. We present results obtained from a study of thermally induced interactions between GaAs and Ge substrates and the metals Pt and Pd. Results of the analysis of multiple layered structures on GaAs and GaAlAs substrate with HIRBS are also discussed.

1. Introduction

The potential advantages of Heavy-Ion Rutherford Backscattering Spectrometry (HIRBS) over conventional Rutherford Backscattering Spectrometry (RBS) using hydrogen or helium ions have been pointed out by several authors and a number of comparative studies have been performed[1-4]. The principal advantage of HIRBS is the improved mass resolution for the analysis of high atomic number samples. Additional advantages which can be exploited in certain applications include increased accessible depth and a smaller minimum detectable limit for impurity concentrations. These advantages have recently become increasingly important for the development of devices using compound semiconductors containing elements of high atomic number. In this paper we present the results of a study of the contact structures on GaAs and Ge with both HIRBS and conventional ^{4}He RBS.

Figure 1(a) shows plots of the 170° backscattering coefficient $K \cong E_1/E_o$ for the case of ^{4}He and ^{16}O projectiles where E_1 is the backscattering energy and E_o is the incident energy of the projectile ions. The increased slope of the ^{16}O curve for target masses A > 50 clearly indicates the improved mass resolution achieved. The curves in Fig. 1(b) show mass resolutions calculated using $\partial M/\partial E$ as derived from the relationships of Fig. 1(a) combined with a typical experimental ion detection energy resolution (full width half maximum) of 15 keV for ^{4}He and 100 keV for ^{16}O. Under these assumptions, the ability to resolve adjacent target isotopes extends to A = 150 for ^{16}O compared to A = 50 for ^{4}He.

2. Experimental

The emphasis of the study was on the use of HIRBS to determine the properties of various layered structures of potential interest in semiconductor devices. Examples which we studied include a Au/Pd contact stucture for high

purity Ge gamma ray detectors, the formation of Pt and Pd intermetallic compounds when interacted with a GaAs substrate, and multilayered contact structures for the use with GaAs devices.

The structures were normally fabricated by vacuum evaporation technique. Interactions between the various constituents were observed following annealing at temperature ranging from 350° to 500°C in N_2 or Ar ambient. In some cases, the samples were analyzed by X-ray diffraction as a verification of the HIRBS measurement. Electrical characterization measurements have also been obtained in some cases but will not be discussed in the present paper.

Rutherford Backscattering measurements were performed using both the 2 MeV Van de Graaff facility($^4He^+$ at 1.5 and 1.8 MeV) and the heavy-ion capability of the 88" cyclotron ($^{16}O^{2+}$ at 20 MeV) at the Lawrence Berkeley Laboratory. A Si surface barrier detector depleted to a depth of 200 μm and with 20 keV FWHM energy resolution for 5 MeV alpha particles was used for α-RBS measurements. A similar detector of annular type was used for HIRBS measurements in order to increase count rates without affecting the kinematics.
The spectrometers were calibrated for energy and system resolution using alpha particles from a ^{244}Cm, ^{241}Am source. The observed energy resolution for ^{16}O at 20 MeV for both detectors was 105 keV.

The incident particle beams were collimated to a 1.5 mm diameter spot size with an angular spread of less than 1°. The scattering angles were 170° for the conventional detector geometry and 176.25° for the annular detector with detection solid angles of 2.7 and 16.45 msr for the two detectors respectively. For HIRBS, typical beam currents ranged from 30 - 100 nA and a total charge between 20 and 50 μC was normally accumulated. For conventional α-RBS, beam currents were usually below 10nA and the accumulated charge ranged from 2 to 4 μC.

3. Results and Discussion

3.1. Au/Pd on Ge system

Figure 2(a) shows backscattering spectra obtained with a 20 MeV ^{16}O beam incident on the 500Å Au /400 Å Pd/Ge samples as deposited and annealed. The samples were tilted to 60° in order to improve depth resolution. The lowering and broadening of the Pd signal and the shoulder formed in the Ge signal indicated that a reaction between Pd and Ge had taken place after annealing at 200° C for one hour. Careful analysis of the height ratio of the Ge shoulder and the Pd signal showed that the atomic ratio of Pd and Ge in the compound formed is 2:1 and therefore the compound was probably Pd_2Ge. Annealing at 150° C for up to four hours showed no compound formation while annealing at 250° C for one to four hours gave the same result as in the 200° C anneal case. This is in agreement with Wittmer et al.[5] who found that in the 100 - 250° C annealing temperature range, Pd_2Ge was the intermetallic compound formed between Pd and Ge. Also from Fig. 2(a), one can see that Au diffused through the Pd_2Ge layer and accumulated at the interface of Ge and Pd_2Ge. The possible structure of the annealed system is shown in the insert of Fig. 2(a).

Figure 2(b) is an α-RBS spectrum of the same annealed sample using the 1.5 MeV ^4He beam. The Ge and Pd signals overlapped and the Au diffusion was not observed. Although interface reaction between Pd and Ge was obvious, the Ge and Pd atomic ratio in the interface layer cannot be measured.

3.2. Pt on GaAs system

Figure 3(a) shows two HIRBS spectra (20MeV ^{16}O) of a 2000 Å Pt on GaAs. The GaAs substrate was n-type doped with ~ $10^{17}/cm^3$ Te. The two spectra represented the layer as deposited and after 60 minutes annealing at 500° C. The step-like profile of the Pt signal in the spectrum of the annealed sample (solid line) clearly indicated the presence of two phases in distinct layers. By

measuring the height ratios of Pt to Ga and Pt to As in the spectrum, these two phases can be identified as PtGa and $PtAs_2$. The $PtAs_2$ appears to be at the GaAs interface while PtGa is at the surface. Kumar[6] reported that it was not possible to react thick (2000 Å) Pt films with GaAs to completion to form PtGa and $PtAs_2$ even after two hours annealing at 500° C. However, complementary X-ray diffraction measurement on the same annealed Pt/GaAs sample showed that PtGa and $PtAs_2$ were the only compounds formed.

As a comparison, 1.8 MeV α-RBS was also performed on the 500° C, 60 min. annealed Pt/GaAs sample and the spectrum is shown in Fig. 3(b). Note that backscattered signals overlapped because of the limited mass resolution of ^4He particles. Owing to this inherent limitation of α-RBS, no information on the types of compound formed could be deduced from the spectrum.

3.3. Pd on GaAs system

Figure 4(a) shows a series of HIRBS spectra of 600 Å Pd on GaAs for the following cases: (i) as deposited, (ii) 40 min. annealing at 350° C and (iii) 100 min. annealing at 350° C cases. Comparing the spectra of the As deposited and the annealed samples, one can see the out-diffusion of both Ga and As. The As moved to the surface while Ga moved to the layer below the surface as the samples were heat treated. Energy loss analysis of the spectra showed that the compounds formed between Pd and Ga and those formed between Pd and As did not form distinct layers. The Pd-As compound appeared on the outer layer while the Pd-Ga compound lay right above the GaAs substrate with a mixture of the two kinds of compounds in the middle layer. As the sample was annealed for longer times, the Pd signal decreased in height and broadened in width while the Ga signal increased in height in the spectrum as shown in Fig. 4(a). This indicated that the compounds formed between Pd and Ga became more Ga rich. However, the outer layer was still a compound of Pd and As. This observation

was confirmed by X-ray diffraction analysis which showed that in the 350° C 40 min. annealed sample, Pd_2Ga, PdGa and $PdAs_2$ were present; while in the 350° C 100 min. annealed samples, the Pd_2Ga almost disappeared totally and the amount of PdGa formed increased.

Backscattering with 1.8 MeV ^4He on the 600 Å of Pd/GaAs annealed at 350° C for 100 min. shown in Fig. 4(b) was not able to reveal the sequence and composition of the different compounds because of significant signal overlapping between the in-diffused Pd and the out-diffused Ga and As.

3.4. Multiple layered structures

Real GaAs devices usually involve contact structures with multiple layers of metal films on GaAs substrates. An example of such a multilayer system is an ohmic contact with layers of Au, Ge, Au, Ni-Cr, GaAs on GaAlAs. Figure 5 shows a comparison of 20 MeV ^{16}O backscattering spectrum with 1.5 MeV ^4He spectrum for this case. The improved detail of the HIRBS spectrum is obvious--all layers were well resolved and the atomic ratio in the Ni-Cr layer can be measured. In the α-RBS spectrum, signal overlapping causes a lot of difficulties in the data analysis. Determination of the layer thickness and Ni-Cr ratio is almost impossible.

4. Conclusions

We have demonstrated the advantages of using high energy heavy-ions (20 MeV ^{16}O) as projectiles for the backscattering analyses of contact structures on Ge and GaAs. The improved mass resolution of heavy-ions made possible the identification of the structures of the different systems as they were heat treated under different conditions. From these studies, it is clear that HIRBS together with a complementary technique such as X-ray diffraction for phase identification is capable of playing an important role in the characterization of contact structures and multiple layered structures on high Z semiconductors.

5. Acknowledgements

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Figure Captions

Fig. 1(a) Kinematic factor K vs. target mass M_2 for ^4He and ^{16}O projectiles calculated for 170° scattering angle.

1(b) Mass resolution vs. target mass as calculated from curves in Fig. 1(a) assuming energy resolution of 20 keV and 100keV for ^4He and ^{16}O respectively.

Fig. 2(a) 20 MeV ^{16}O RBS spectra for a Au/Pd on Ge system. The solid spectrum represents the 200° C annealing for one hour case. The insert in the figure shows the possible structure of the system after annealing as measured by HIRBS.

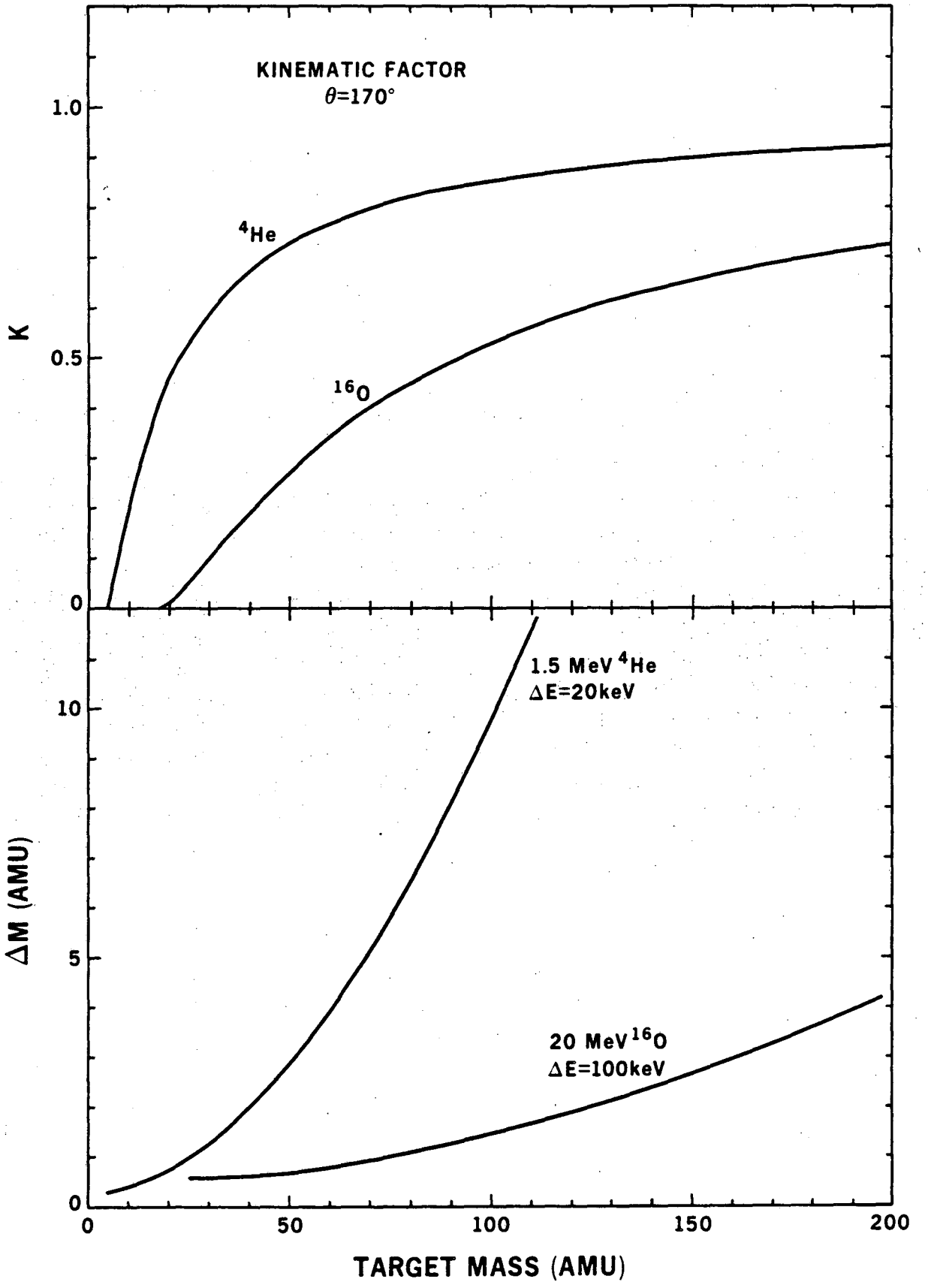
2(b) 1.5 MeV ^4He RBS spectrum of the same system after one hour annealing at 200° C.

Fig. 3(a) Backscattering spectra for 20 MeV ^{16}O ions incident on the 2000 Å Pt/GaAs system.

3(b) 1.8 MeV ^4He RBS spectra of the same system.

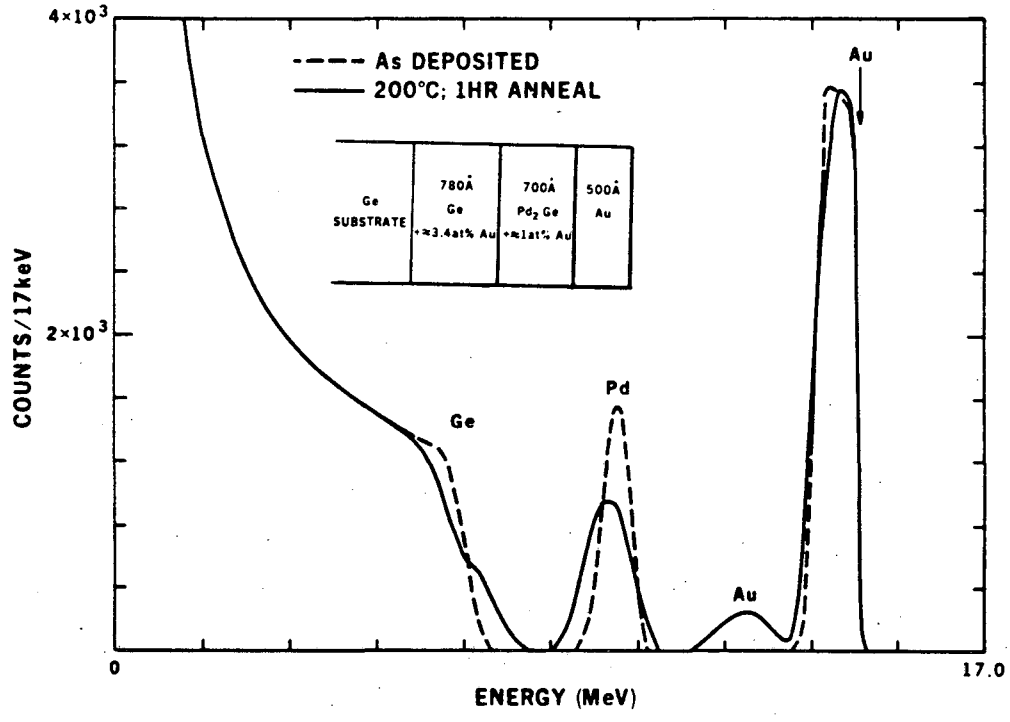
Fig. 4(a),(b) Backscattering spectra comparing ^{16}O and ^4He ions RBS for 600 Å Pd on GaAs substrate. The arrows show the surface edges of the corresponding elements.

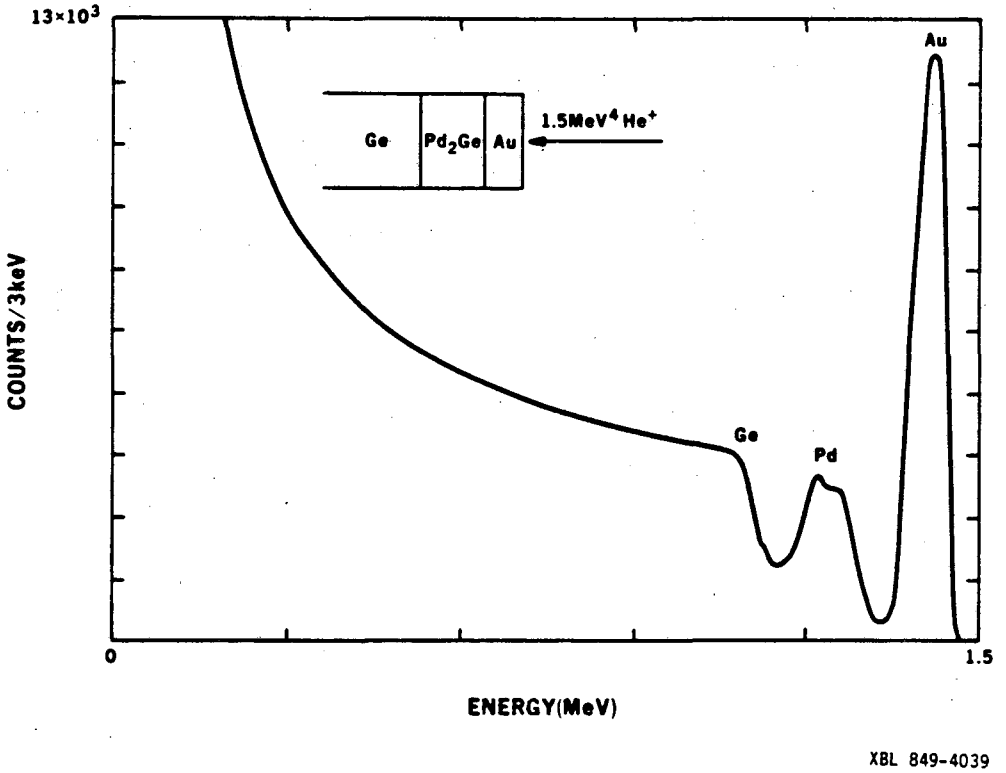
Fig. 5. Backscattering spectra comparing ^{16}O and ^4He ions RBS for an ohmic contact structure on GaAlAs substrate.



XBL 834-9457

Figure 1.





XBL 849-4039

Figure 2.

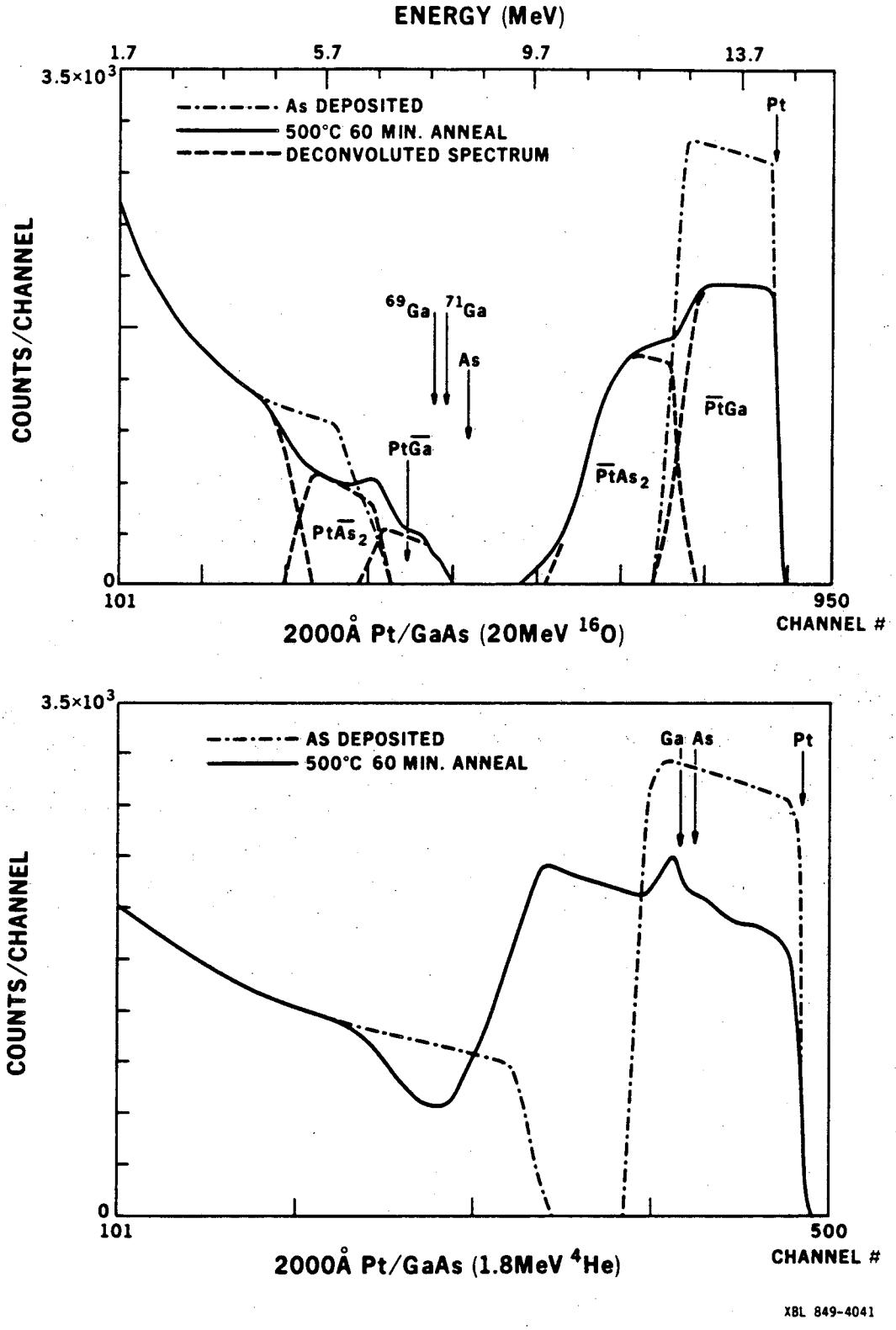

ENERGY (MeV)
1.7
5.7
9.7
13.7
3.5×10³
As DEPOSITED
500°C 60 MIN. ANNEAL
DECONVOLUTED SPECTRUM
Pt
COUNTS/CHANNEL
⁶⁹Ga
⁷¹Ga
As
PtGa
PtAs₂
PtGa
PtAs₂
0
101
950
CHANNEL #
2000Å Pt/GaAs (20MeV ¹⁶O)
3.5×10³
AS DEPOSITED
500°C 60 MIN. ANNEAL
Ga As
Pt
COUNTS/CHANNEL
0
101
500
CHANNEL #
2000Å Pt/GaAs (1.8MeV ⁴He)
XBL 849-4041

Figure 3.

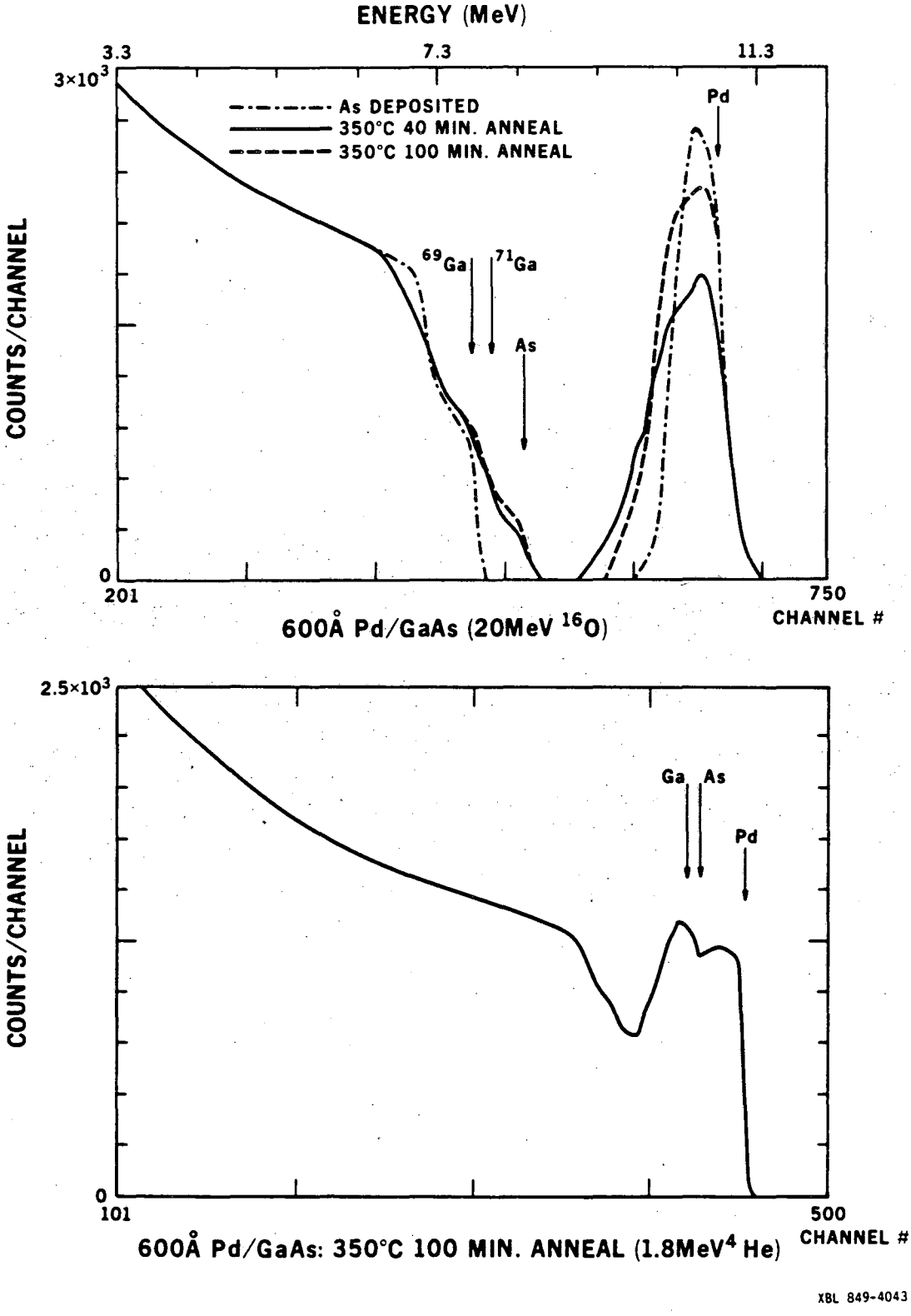
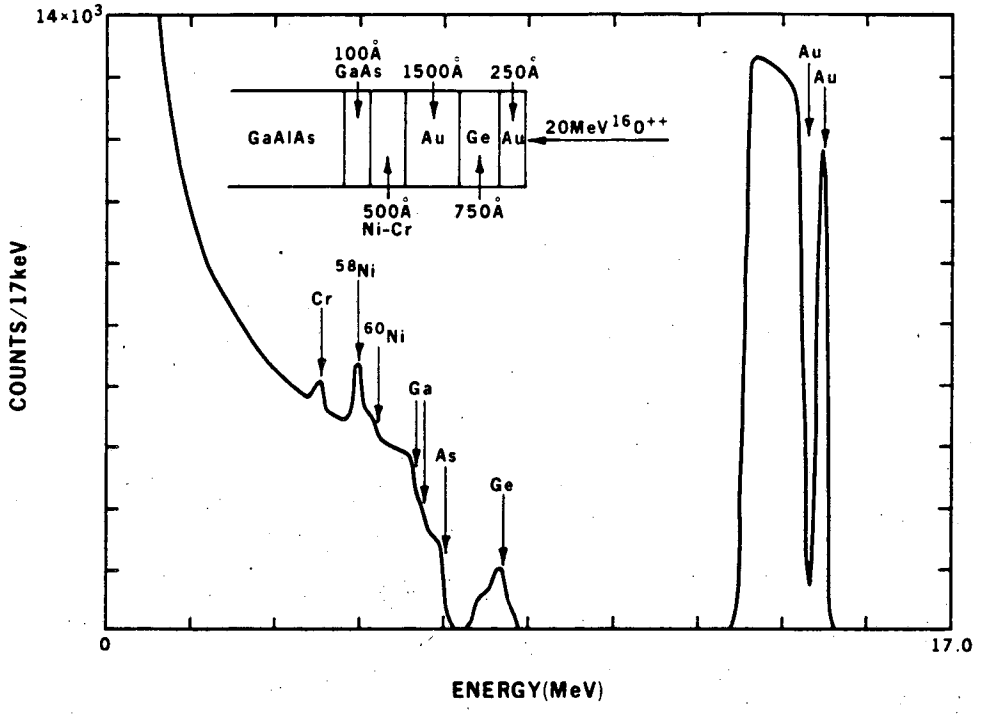
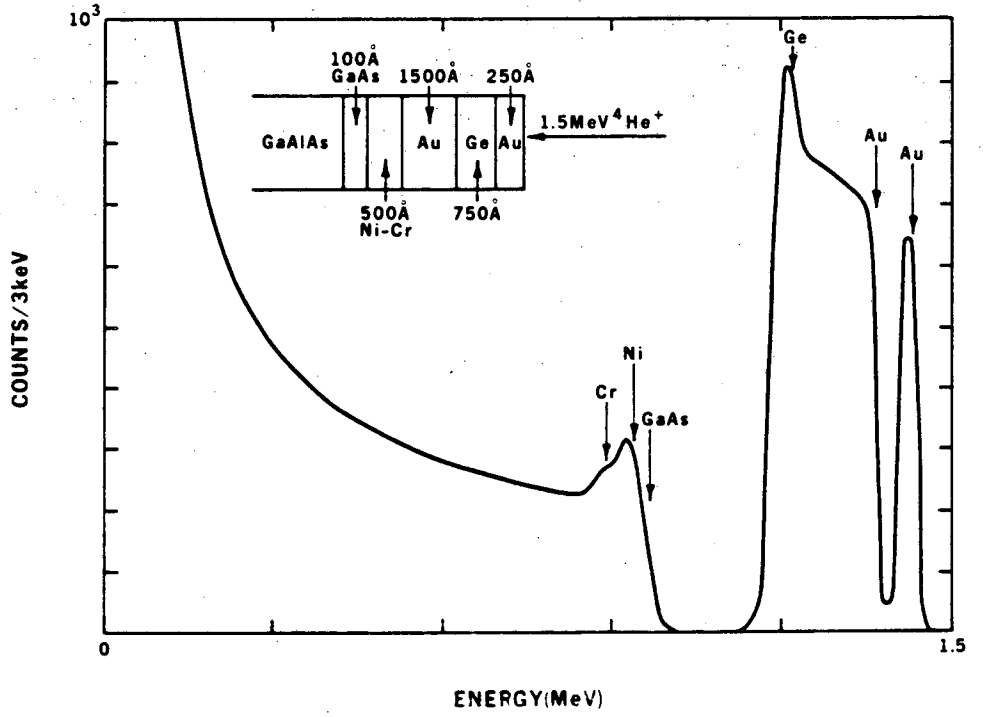

ENERGY (MeV)
3.3
7.3
11.3
3×10^3
0
201
750
CHANNEL #
COUNTS/CHANNEL
As DEPOSITED
350°C 40 MIN. ANNEAL
350°C 100 MIN. ANNEAL
69Ga
71Ga
As
Pd
600Å Pd/GaAs (20MeV 16O)
2.5×10^3
0
101
500
CHANNEL #
COUNTS/CHANNEL
Ga
As
Pd
600Å Pd/GaAs: 350°C 100 MIN. ANNEAL (1.8MeV4 He)
XBL 849-4043

Figure 4.





XBL 842-632

Figure 5.

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