

Oxygen Content and Depth Profiling in Silicon Surface Technology Studied by the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ Resonance at 3.045 MeV

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Abstract

Oxygen content and depth profiling in silicon surface technology studied by the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ resonance at 3.045 MeV. G. Possnert, C. Fahlander, B. Orre (Institute of Physics, 751 21 Uppsala, Sweden) and H. Norde, S. Petersson, P. A. Tove, (Institute of Technology, 751 21 Uppsala, Sweden).

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The use of the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ elastic scattering resonance reaction for the study of low concentration of oxygen such as found in interfaces in silicon technology is described. We have investigated the depth resolution and the limit of the sensitivity that can be obtained with this method. The method has been applied to the study of Al_2O_3 -Cr "sandwich" film structures and to Au and amorphous Ge contacts to silicon.

1. Introduction

In an earlier publication we have pointed out the application of the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ scattering peak to the study of thin oxide interface layers in electronic device studies [1]. In the present publication we have extended this study, in particular studying the depth resolution that can be obtained with this method, and improving the sensitivity by utilizing channeling. One aim of the study has been to investigate contacts to monocrystalline silicon, including Au, amorphous Ge, PtSi and surface barrier detectors. We also studied sandwich structures consisting of Al_2O_3 layers separated by Cr layers, for studying the depth resolution.

2. The method

As the principle has been more fully described elsewhere [1, 2] we will only discuss briefly some aspects pertinent to the present applications. In Figs. 1(a) and 1(b) we show typical α particle backscattering spectra, from scattering α particles of energies around 3 MeV, from an Al plate covered with a thin Al_2O_3 oxide, fabricated by anodic oxidation [3]. The purpose of Fig. 1 is to demonstrate the effect of the sharp $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ resonance (width approximately 20 keV) on the Rutherford backscattering spectrum. While Fig. 1(a) is for an incoming α energy of ≈ 3.025 MeV, which is slightly off resonance, we have in Fig. 1(b) the energy 3.045 MeV, which is on the peak of the resonance. The Al_2O_3 layer is very thin. Figure 1(b) clearly demonstrates that we can radically enhance the sensitivity for oxygen detection (with approximately a factor 35).

2.1. Calibration procedure

In Fig. 2 we summarize the result of taking a large number of spectra of the type shown in Fig. 1, for different Al_2O_3 samples, of thickness 30 Å, 90 Å, 130 Å and 240 Å. We plot in Fig. 2 the normalized area of the oxygen distribution for different energies. After subtracting the background, the counts in the oxygen peak were normalized to the background which is due to α particles scattered against Al atoms in the substrate, and in the film. The ordinate Y in Fig. 2 is the corresponding quotient and its value reflects the oxygen content. We observe in Fig. 2 the slight shift of the peak towards higher energy, when Al_2O_3 thickness increases. The maximum of the curves are associated with the center of the Al_2O_3 layer and to reach the center

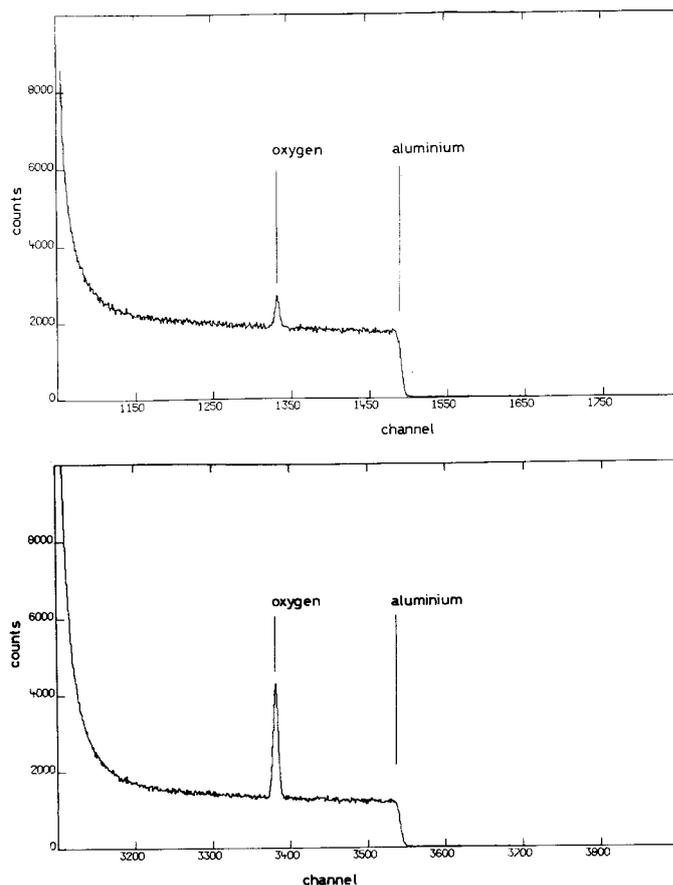


Fig. 1. (a) α backscattering spectrum from 240 Å Al_2O_3 , on Al, below resonance energy. (b) Same, but at resonance (3.045 MeV α).

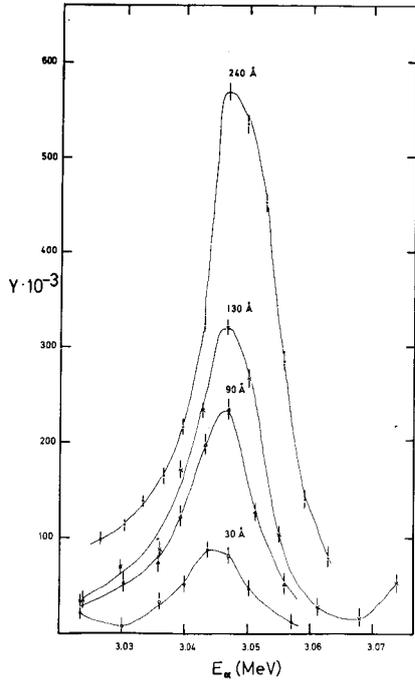


Fig. 2. Normalized oxygen content as a function of α energy, for Al_2O_3 layers of different thickness.

requires a somewhat higher energy when the thickness is increased. Since the width of the oxide (measured in equivalent energy loss for the α particles) is small compared to the width of the resonance the peak values in Fig. 2 can be used as a measure of the oxygen content. The result of this simplified analysis is shown in Fig. 3 where normalized oxygen content Y is plotted versus the film thickness. This can be used as a calibration standard. In fact, this calibration can be used also for our later studies of thin oxide films on a silicon background, since it is found that although Al and Si have slightly different backscattering cross-sections, this is balanced by the fact that they also have slightly different stopping powers.

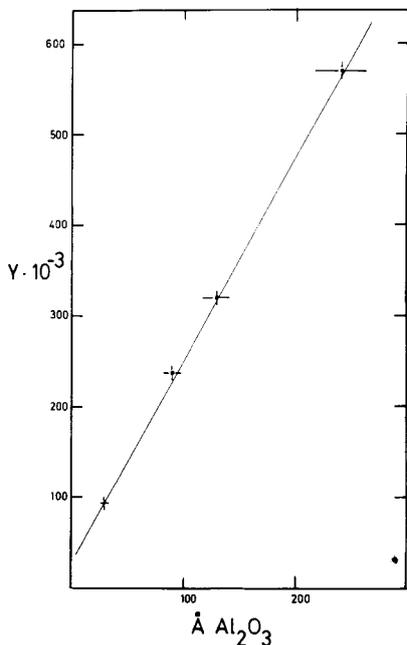


Fig. 3. Calibration curve for oxygen content.

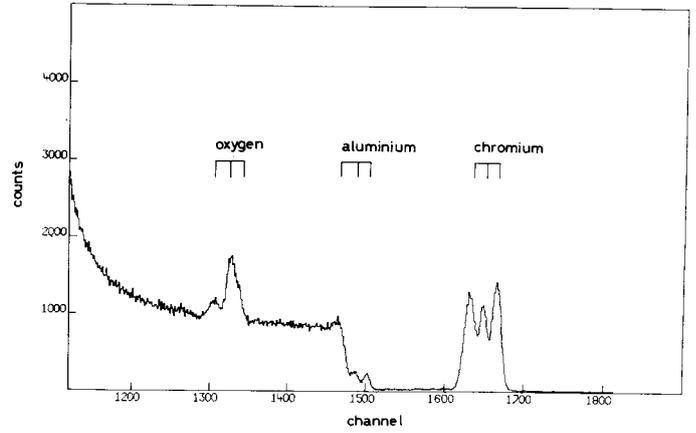


Fig. 4. α backscattering spectrum from a sandwich structure consisting of 3 Al_2O_3 layers intermixed with 3 Cr films, on silicon.

3. Demonstration of depth resolution

Figure 4 shows the spectrum obtained for a sandwich structure consisting of the following layers: (counting from the substrate): Al_2O_3 , Cr, Al_2O_3 , Cr, Al_2O_3 , Cr. Deposition was made on a (111) silicon wafer. The thickness of each layer was of the order of 500 Å. The spectrum in Fig. 4 is taken for an α energy which places the oxygen resonance approximately in the middle of the second Al_2O_3 layer. This is seen from the fact that the corresponding oxygen distribution is much higher in relation to the oxygen distributions resulting from the other Al_2O_3 layers, in contrast to the Al peaks which are all of about the same magnitude.

The distributions due to the three Cr layers are all clearly separated. We see, however, that the middle Cr layer is slightly thinner than the other ones which is reflected in the separation of the peaks in the concentration profile of Fig. 5. Here it is seen that the distance between the two highest peaks, which stem from the Al_2O_3 layers on both sides of the middle Cr film is smaller than the separation between the other Al_2O_3 distributions. The highest-energy peak includes the native SiO_2 layer (in addition to the inner-most Al_2O_3 layer). One interesting observation in Fig. 5 is that the outer-most Cr layer has a noticeable amount of oxygen, which may be adhered to the surface, or possibly be due to chromium oxide. It is not possible to distinguish between the two possibilities by looking at the high energy side of the Cr distribution in Fig. 4. Since the layers are too thin we cannot expect to see any plateau of the type seen for oxide formation, in ordinary RBS spectra.

The conclusion from Fig. 5 is that we have not yet reached

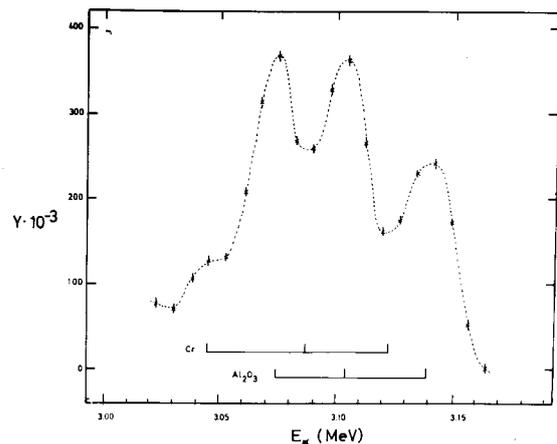


Fig. 5. Oxygen depth profile for the sample of Fig. 4.

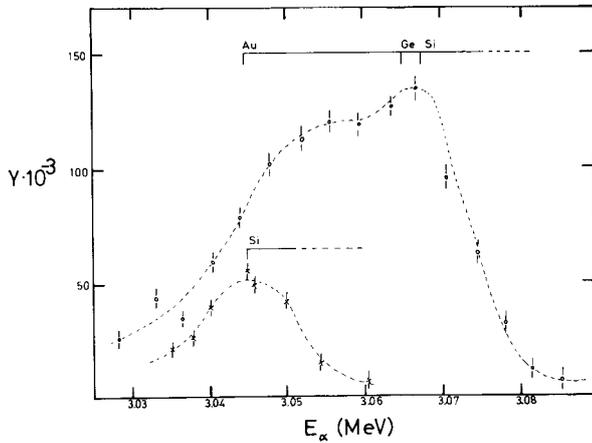


Fig. 6. Oxygen depth profile for two different areas of a Si wafer. \circ is for an area covered with a Ge layer (100 Å), with an Au film (≈ 340 Å) on top, \times is for a bare Si surface.

the limits of depth resolution. We estimate from Fig. 5 that we would be able to distinguish between oxygen distributions separated by a chromium film of thickness of ≈ 150 Å, corresponding to 10 keV. This is in agreement with the consideration that half of the full width at half the maximum of the resonance peak is 10 keV. It is interesting to note that the resolution in fact is not determined by the detector resolution, but by the width of the resonance. In fact the resolution can even be improved (expressed in thickness) by tilting the sample [4].

4. Contacts on silicon

The presence of oxide interface layers in Si contacts can play a dominant role in determining their electric behaviour. However, the amount of oxygen involved often are so small that few methods permit detection. The present technique has sufficient sensitivity and at the same time has the advantage of being non-destructive. Figure 6 which is from [1] shows an energy scan from backscattering against a silicon wafer having two different surface regions (for details see [1]). The lower curve is for scattering against a naturally oxidized Si surface and verifies the existence of a native oxide layer. The upper curve, which is for scattering against a region covered with an amorphous Ge layer, with an Au layer on top, shows that, in addition to the native oxide distribution starting at about 3.05 MeV, additional oxygen is introduced in the Ge film, and in the Au film. Because the films in Fig. 6 are too thin

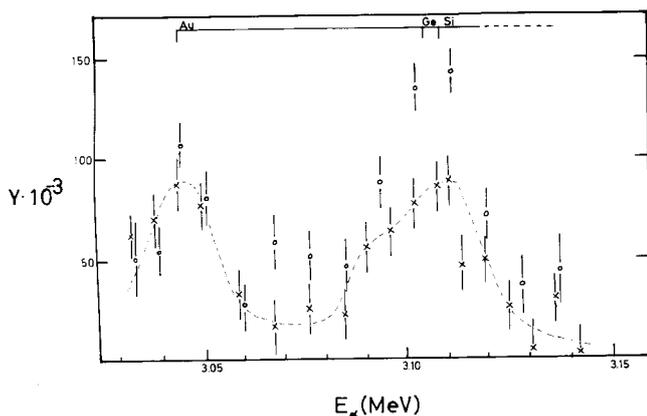


Fig. 7. Oxygen depth profile similar to Fig. 6 but for two samples with an Au film thickness of 1000 Å. One sample (\times) was dipped in HF before contact preparation.

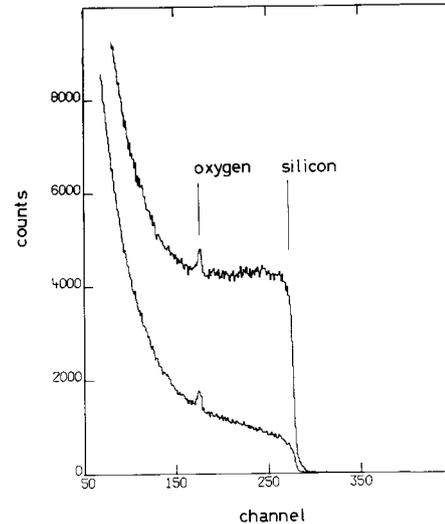


Fig. 8. α backscattering spectra for naturally oxidized, (111) oriented Si wafer. The upper curve is for random orientation, the lower curve with alignment for channeling.

we cannot tell any details. To clarify, we made a similar structure but with a thicker Au film (about 1000 Å; the Ge thickness was 3–400 Å). The results from studying two different samples are shown in Fig. 7. One wafer was dipped in HF before the deposition of the GeAu layers (cross marked) while the other (ring marks) was not (i.e., it had the same surface treatment as that of Fig. 6). From Fig. 7 it is clear that we have oxygen absorbed on the Au surface (at 3.045 MeV). Little or no oxygen is to be seen inside the Au layer, but an increase is observed when approaching the Ge layer and the Ge–Si interface. It can be seen that the HF treatment has reduced the native oxide on the silicon with approximately a factor 2. There is some indication in Fig. 7 that oxygen has diffused into the Au film.

4.1. Enhancing detection sensitivity by using channeling

To study the oxygen concentration on single crystals like silicon it is advantageous to use channeling. Channeling decreases the background from the backing, as demonstrated in the lower curve of Fig. 8, which is taken for a Si wafer with native oxide. A proper, commonly used criterium for deciding whether we can detect a peak from the background, is that the signal should be at least three times the standard deviation in the background. Thus, decreasing the background with a factor of approximately 4, as in Fig. 8, we improve the detection limit by a factor of 2. Channeling in Fig. 8 is not optimum. Background reduction ratios of up to 100 can be obtained under favourable conditions.

5. Future studies

We have shown that the method is suitable for analysis of thin film structures deposited in different ways, e.g., by evaporation and by sputtering. Future investigations are aiming at studying the influence of temperature treatment, and of the influence of oxide films of the formation of silicides. The method may also be suitable for studying aging phenomena in detectors, e.g., surface barrier detectors. As an example we found that an Ortec detector had no oxygen adhered to the Au surface, but only in the interface (approx. 2×10^{16} oxygen atoms cm^{-2} were present).

Acknowledgement

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References

1. Petersson, S., Norde, H., Possnert, G. and Orre, B., Nucl. Instr. and Meth. **149**, 285–288 (1978).
2. Mezey, G., Gyulai, J., Nagy, T., Lotai, E. and Manuba, A., Ion Beam Surface Layer Analysis, in O. Meyer, G. Linker and F. Käppeler (eds.), Plenum Press, New York, 1976, Vol. 1, p. 303.
3. Davies, J. A., Friesen, J. and McIntyre, J. D., Canadian Journal Chemistry **38**, 1526 (1960).
4. Williams, J. S., p. 223 in [2].