OXYGEN DISTRIBUTION PROFILES IN THIN EVAPORATED CONTACTS ON SINGLE CRYSTAL SILICON

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The nuclear resonance in the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ elastic scattering reaction at 3.045 MeV has been used in concentration profile measurements of oxygen in thin-film structures.

The concentration profile can be deduced from an energy scan of the incoming α -particles, thus shifting the resonance to different depths in the sample. The method has been applied to studies of the structures (a) an etched Si-surface, (b) Au evaporated on Si, and (c) a Au-Ge-Si structure. Evidence is presented for the presence of oxygen in the Au layer and in the Ge layer.

1. Introduction

The electrical properties of metal-semiconductor contacts are strongly dependent on the nature of the interface between metal and semiconductor^{1,2}). With respect to the formed interface barrier height it has been found that the interface oxide is probably the single most important property. These naturally formed oxide layers are of thickness in the range 10–50 Å.

It is also well known that some metal-semiconductor contacts, such as the Au-nSi contact in standard surface barrier detectors, need a period of stabilization in air before the barrier has increased to its final value. It has also been shown that an oxygen backfill after the gold evaporation gives the best results when fabricating surface-barrier detectors³).

For investigation of the oxygen content in these contacts, there are besides conventional RBS analysis⁴) different useful techniques, such as the (d, p) and (p, α) nuclear reactions⁵), the (p, p) resonant proton scattering⁶), the (d, α) nuclear reaction⁷) and the (α , α) resonance⁸). In this paper we have used the last mentioned: the $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ resonance at 3.05 MeV. The method has advantages over other techniques in the analysis of thin-layer

structures, as the resonance is symmetric⁸) and moderately narrow, (<20 keV) and the relatively high stopping power for α -particles implies a comparatively good depth resolution. The sensitivity, however, is not as good as that obtained from nuclear reactions.

2. Experimental

2.1. SAMPLE PREPARATION

The investigated structures were made with standard etching and evaporation techniques.

The silicon slices of n-type were etched in CP6 (25% HF, 25% CH_3COOH , and 50% HNO_3) for 3 min and quenched in distilled water. After the etch they were stored for a period of about 24 h after which the evaporations were performed at a pressure of 10^{-5} torr.

Three different structures were investigated:

- 1) Si-surface,
- 2) Si-Au, evaporation rate 50–100 Å/min, and
- 3) Si-Ge-Au (evaporation rate Ge, 200 Å/min and Au as above).

The structures were made on the same slice with standard masking techniques (fig. 1). The analysis of the structures was performed about three days after the fabrication.

To calibrate the resonance yield for different oxygen contents, we fabricated a series of samples with well known oxide thicknesses from 30 Å to 240 Å. The oxides formed were Al_2O_3 on Al plates in an anodizing bath. The method is described in ref. 9. The stoichiometry of the formed oxides is $\text{Al}_2\text{O}_{(3.05 \pm 0.05)}$ ¹⁰). On top of the oxide layers, a gold

Fig. 1. Sample configuration. The substrate is etched single crystal silicon.

IV. ANALYSIS BY NUCLEAR REACTIONS

layer was evaporated of the same thickness as the layers of structure (2) and (3).

2.2. MEASUREMENTS

The experiments were performed at the Van de Graaff accelerator, Studsvik, Sweden, with standard backscattering equipment.

The $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ resonance yield has its maximum at a scattering angle of 180° as displayed in fig. 2; this property determines the geometry of our experiment. A 300 mm^2 annular surface barrier detector was used (resolution approximately 30 keV for $3\text{ MeV } \alpha$). A collimator of diameter 17 mm was placed in front of the detector, and the distance between collimator and target was measured to be 74 mm . This arrangement corresponds to a back-scattering angle of 113.5° to 173.5° .

The resonance yield (Y) was defined as the ratio of the oxygen peak area to the integrated area of Al or Si distribution between two fixed channels. This yield was determined in an energy scanning measurement, where the α -energy was changed in steps of about 2.5 keV over the resonance.

The resonance yield curves for the well determined aluminium oxide thicknesses are shown in fig. 3. Since in this case the resonance is broad compared to the energy spread of the beam (less than 1 keV) as well as the energy loss and straggling in the oxide layers (see insert of fig. 3) the yield at the maximum point in the scan is propor-

Fig. 2. The $^{16}\text{O}(\alpha, \alpha)^{16}\text{O}$ differential scattering cross section at the resonance energy 3.045 MeV as a function of scattering angle (dashed line) and the extrapolated Rutherford cross section (solid line) in c.m. coordinates.

Fig. 3. Resonant alpha scattering yield Y defined as the ratio of oxygen peak area to background for different anodized Al_2O_3 thicknesses on Al-foils as a function of accelerator-beam energy. The shift in resonant energy to 3.065 MeV is caused by the energy loss in the top $\psi\text{ Au}$ layer.

Fig. 4. Maximum of the resonance curves in fig. 3 as a function of Al_2O_3 thickness and oxygen content.

tional to the oxygen content. Fig. 4 shows the result of the calibration procedure, where oxygen content as a function of maximum yield is plotted. The errors in the thickness values for the Al_2O_3 layer are indicated.

The deviations of the two lower points, corresponding to the 30 Å and 50 Å Al_2O_3 layers, are probably caused by the tendency these layers have of increasing their oxide thickness when stored in air. (The layers were fabricated the day before the measurements.)

After the calibration, the layered structures were analyzed by a similar energy scan. At each energy set of the incoming beam, a spectrum of the backscattered α -particles was taken to determine the yield. In fig. 5 three spectra are shown for the different structures. Beam current was typically 5 nA

to avoid pileup effects, and the collecting time at each energy was five to fifteen minutes.

From the backscattering spectra the content of Ge and Au was calculated with standard RBS methods¹¹).

3. Results and discussion

In fig. 6 are shown the results of the energy scans performed on sample 12 consisting of the three structures as shown in fig. 1. The Si-substrate is 100 $\Omega\cdot\text{cm}$ n-type material.

The thicknesses of the evaporated layers were measured from the spectra shown in fig. 5 to be 350 Å and 100 Å Ge (assuming bulk densities). The corresponding energy losses are indicated in fig. 6 for sample C. (Energy loss data from ref. 12 are used.). The resonance yield of the bare silicon surface indicates an oxide thickness of about 30 Å (if stoichiometric SiO_2 is assumed).

The yield curve from the Au-Si and Au-Ge-Si structures has been analysed semi-quantitatively with the resonance cross section $\sigma(E)$ given in ref. 8 applied on different assumed oxygen distributions. A comparison of the experimentally obtained yield curve and the theoretically calculated curves has then given us a semi-quantitative picture of the oxygen distributions in the layers. In the Si-Au case we found that the oxygen content at the silicon-gold interface is of the same order as before the gold evaporation, but there is a more or less continuous oxygen distribution throughout the gold layer: total amount about 1×10^{16} at-

Fig. 5. Backscattering spectra at or near resonance for the three structures (from top) (1) Si-surface, (2) Au on Si, and (3) Au-Ge-Si structure. The areas of the oxygen peaks in a spectra are proportional to oxygen content in a layer of thickness corresponding to the resonance width at the depth where the resonance occurs.

Fig. 6. Energy scan of the structures (a) Si-surface, (b) 340 Å Au on Si, and (c) 340 Å Au and 100 Å Ge on Si.

oms/cm². In the Ge-Au-Si structure, it was found that the oxygen content in the Ge-layer and the oxygen content at the Si surface add up to about 1.6×10^{16} atoms/cm². The oxygen content in the gold bulk and on the gold surface has increased compared to structure (2). The increase of oxygen because of the added germanium layer is probably from a slight oxidation during the evaporation of the germanium and on an oxidation of the Ge surface during the vacuum break before the Au-evaporation.

These preliminary results show a promising analytical technique that could be applied to semiconductor technology and metallurgy. A detailed analysis of oxygen contents in layered structures prepared under various conditions is in progress. To enhance sensitivity and accuracy a goniometer for alignment of the silicon substrate will be used, permitting channeling.

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