Improved characterization of diffusion in ohmic contacts using Backside SIMS

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Abstract

Secondary Ion Mass Spectrometry (SIMS) is a proven analytical tool for materials characterization. Backside SIMS was used successfully to study the diffusion of a Au/Pt/Ti metal stack on a laser diode as well as to identify unintentional p-type doping. We will illustrate the excellent control of polishing depth with minimal surface roughness and excellent planar control.

INTRODUCTION

Secondary ion mass spectrometry (SIMS) is a materials analysis technique which can determine the surface and in-depth concentrations of constituents in high technology materials with high precision, sensitivity and accuracy. SIMS techniques and methods have provided state-of-the-art chemical analysis of silicon based semiconductors for more than twenty years[1] and can achieve nanometer depth resolution in depth profiling modes of operation and part per trillion detection sensitivities in bulk analysis of semiconductors.

Primary ions are employed to sputter the surface and sensitive mass spectrometry techniques allow for the detection of mass separated secondary ions. Ion beam mixing and surface roughness primarily limit the depth resolution[2]. The main component for ion beam mixing is the impact energy of the sputtering ions. The higher impact energy increases the penetration depth and adversely influences the depth resolution. An uneven surface allows for the simultaneous collection of secondary ions from various depths. Unfortunately the sputtering mechanism may introduce roughening of the crater bottom, especially in poly-crystalline materials where material is removed along the crystal orientation. This results in a significant degradation of the depth resolution and renders the data useless to evaluate the diffusion of ohmic contact materials into the underlying semiconductor. The presence of metal contamination by diffusion in semiconductor devices is known to affect the performance.

Several techniques, such as the use of oxygen flood and decreased impact angle, have been developed to minimize this effect often at the expense of reduced sputter rates. Rotation of the sample during analysis is very effective on metal films[3]. However, this method is of limited practical use due to poor throughput as only one sample can be processed at a time and difficulties with aligning the sample holder with the extraction optics which results in signal modulation.

Backside SIMS avoids these problems by first polishing away the surface layers or substrate down to the depth of interest and secondly profiling from the backside through the semiconductor or substrate into the metal film.

EXPERIMENTAL

All SIMS data were acquired using a CAMECA 4f sector SIMS instrument.

The first example is a laser diode with ohmic contact on the wave-guide. Figure 1 shows a depth profile of the metal contact layers that was acquired by sputtering from the front of the sample. The Ti profile shows a double peak which is due to matrix effects and a slowly decaying signal (due to sputter roughening). The curve extends into the semiconductor layer and settles at a level which is significantly higher than the instrument background. The Au profile also suggests a high level of Au in the semiconductor structure.

The results of the Backside SIMS analysis are shown in figure 2 with the depth scale reversed to allow for easy comparison to the initial data. The Au, Pt and Ti profiles indicate a sharp drop from the maximum in the recorded values in the contact layers to the much lower background levels in the semiconductor. The laser diode was mounted upside down on a substrate with epoxy glue. It was polished on an Allied High Tech Products, Inc. MultiPrep tool with Dia-Grid Diamond Discs. The polishing was completed over several stages while changing the Diamond Disc from coarse to fine until about one micron of material remains before the area of interest. The surface was polished parallel to the initial surface to within 0.01°. A larger angle would adversely impact the depth resolution.

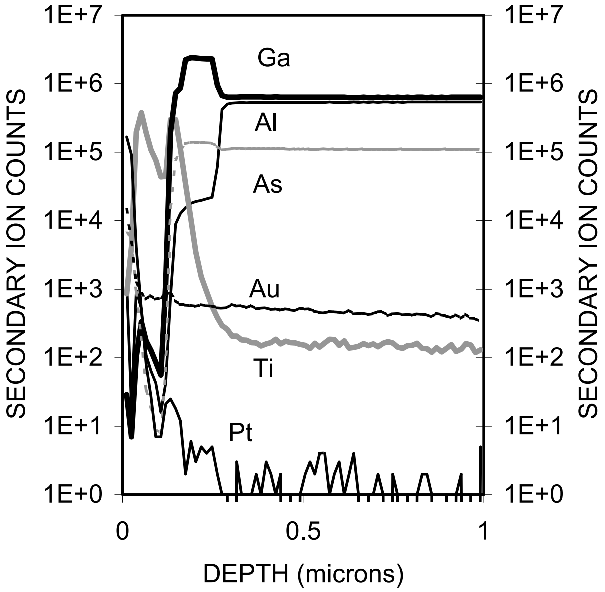

Figure 1 SIMS depth profile of the metal contact layers that was acquired by sputtering from the front of the sample

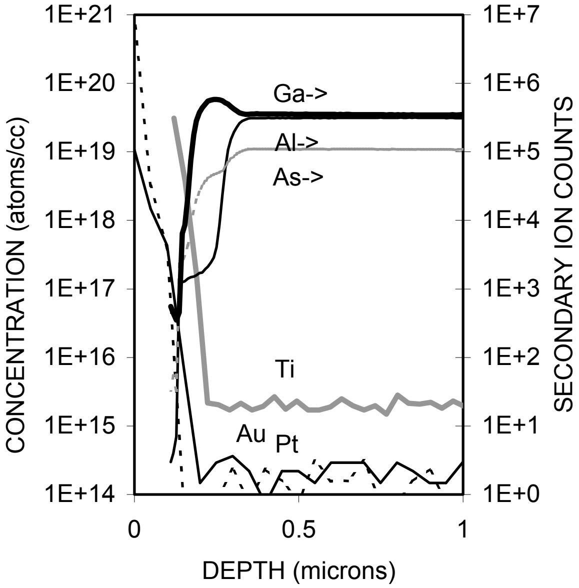

Figure 2 Backside SIMS depth profile of the metal contact layers

A second problem of unintentional doping was investigated for the laser diode. Profiling for Zn, a p-type dopant, through the contact layers was attempted without success. The interference from memory effects of the metal layers is too high to detect low concentrations of Zn. The Zn depth profiles with detection limits of 2E+15 at/cm3 from two lasers diode are plotted in figures 3 and 4. The unintentional doping of Zn at a concentration of about 1E+18 at/cm3 near the active region is clearly detected in the "Bad" device.

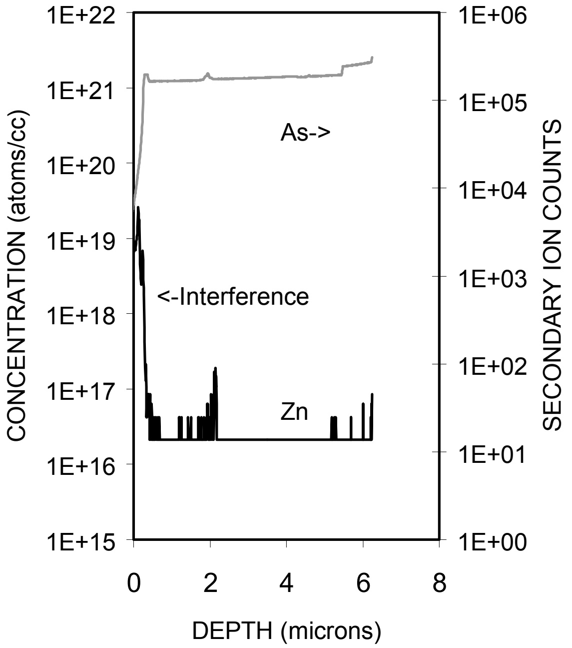

Figure 3 Backside SIMS depth profile of Zn in "Good" device

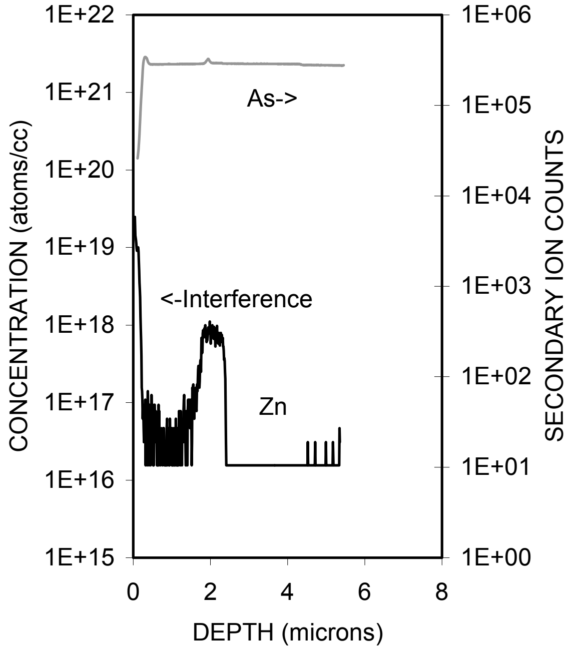

Figure 4 Backside SIMS depth profile of Zn in "Bad" device

A third example of the merits of Backside SIMS is illustrated in the two graphs above. A 350 micron thick substrate with laser diode was polished down to about 1.5 microns from the area of interest. The issue is whether there is any In present at the interface between the epitaxial buffer layer and the GaAs substrate. Figure 5 shows a conventional SIMS depth profile of the In concentration throughout a laser diode structure. The high background signal in the GaAs substrate is due to memory effects as the top epi layers contain In at matrix levels. Figure 6 shows the Backside SIMS depth profile of the In concentration when profiling from the back into the epi layers. The depth resolution is 100 Å per decade and a low background for In was achieved. The data clearly show that there is some In contamination present at the epi/substrate interface.

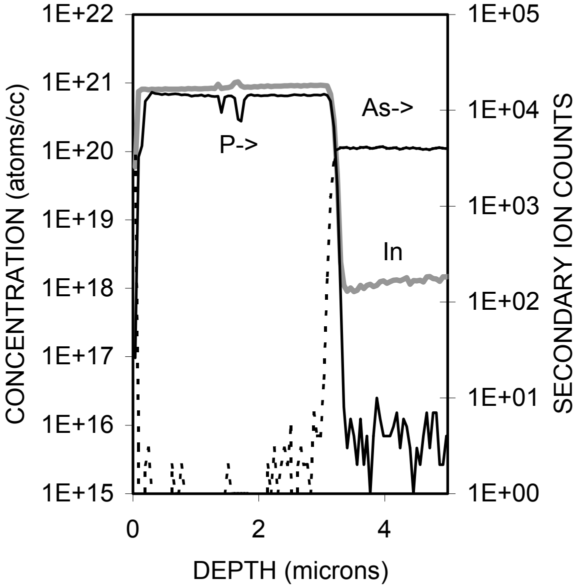

Figure 5 SIMS depth profile of In that was acquired by sputtering from the front of the laser diode

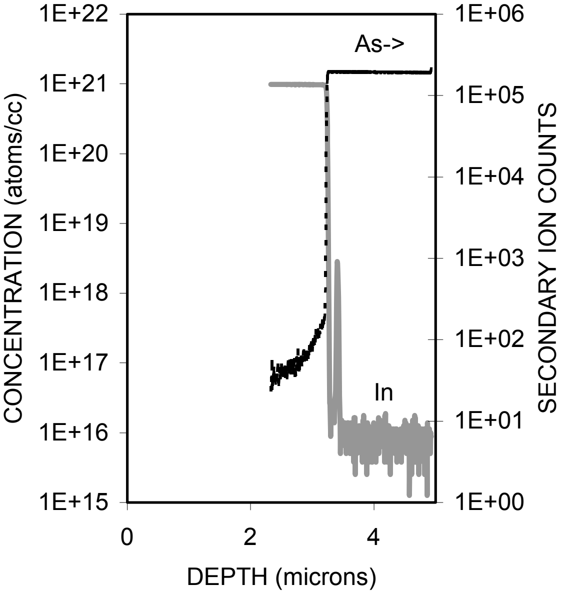

Figure 6 Backside SIMS depth profile of In in laser diode

CONCLUSION

The data acquired by Backside SIMS confirmed that there was no measurable diffusion of the metal contacts into the semiconductor. Also, it was illustrated that contaminants can be measured at low levels and excellent depth resolution can be achieved after polishing away the majority of the material.

Backside SIMS offers a powerful extension of the mature SIMS technique to study materials issues which were previously not possible or were deferred to less sensitive techniques for the lack of a practical SIMS solution.

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