DETERMINATION OF BORON BY THE NEUTRON DEPTH PROFILE (NDP) TECHNIQUE FOR VLSI PROCESSING APPLICATION

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Borophosphosilicate glass (BPSG) has been used for its improved reflow properties compared to low temperature oxide (LTO) in planar technology. Thin films of BPSG were deposited by a low-pressure chemical vapor deposition process. The boron content was determined by NDP. In addition, from the NDP spectrum the depth profile of boron and the thickness of the film were also determined. In the NDP technique, samples, typically silicon wafers with 500 nm thick BPSG film, were exposed to a highly-thermalized neutron beam. Generated by the \(^{10}\text{B}(n,\alpha)^{7}\text{Li}\) reaction, isotropically emitted monoenergetic \(\alpha\)-particles of 1.47 MeV were counted in an evacuated in-beam analysis setup. The energy loss of the \(\alpha\)-particles in the film was proportional to the depth at which the nuclear reaction took place. The energy spectrum of the \(\alpha\)-particles, therefore, was a direct result of the boron depth profile, and the area under the curve was a measure of the total number of boron atoms in the film. This unique nuclear technique provided an excellent method for optimizing the composition of the BPSG film for device processing.

Introduction

Borophosphosilicate glass (BPSG) has been used for its improved reflow properties compared to low temperature oxide (LTO) in planarization process. At Eastman Kodak Company, we have used BPSG to reduce the failure rates due to re-entrant profiles /1/ in semiconductor devices. However, it was very important to be able to characterize BPSG composition, so that proper deposition conditions can be set.

Materials and methods

Thin films of BPSG were deposited using a low-pressure chemical vapor deposition process. A typical film was about 500 nm thick. The silicon wafers were placed in boats inside the evacuated chamber where \(\text{SiH}_4\), \(\text{O}_2\), \(\text{PH}_3\), and \(\text{BCl}_3\) gases were introduced. The temperature was maintained at 420 \(^\circ\text{C}\) while the pressure was set at 465 mPa during deposition. Both \(\text{SiH}_4\) and \(\text{O}_2\) flow rates were maintained at a constant level, while \(\text{PH}_3\) and \(\text{BCl}_3\) flow rates were varied to obtain various levels of P and B in \(\text{SiO}_2\) (LTO).

The purpose of the present study was to correlate the flow rates of \(\text{BCl}_3\) under a given set of conditions to the atomic % of B in...
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the BPSG layer. In addition, it was also necessary to obtain depth distribution profiles of B in the film, so that any nonuniformity of deposition could be corrected.

Neutron depth profiling (NDP) /2/ was used to determine the boron content and the uniformity of the boron distribution in the BPSG. The NDP set by the NBS, Washington, D.C. was used for the measurement.

Typically, our samples were 5000 Å thick BPSG film deposited on 4" silicon wafers. The sample was exposed to a thermalized neutron beam. The beam spot was 10 mm in diameter. The experimental setup /3/ is shown in Fig. 1. The neutron intensity of the beam used was $3 \times 10^8$ n cm$^{-2}$ s$^{-1}$. Boron undergoes the well known $^{10}$B $(n,\alpha)$ $^7$Li nuclear reaction with thermal neutron. This produces monoenergetic $\alpha$-particles of energy 1.47 MeV. Following the nuclear reactions, $\alpha$-particles were emitted isotropically. A surface barrier detector was used to count the $\alpha$-particles as they were given off the surface of the BPSG film. Since the $\alpha$-particles were monoenergetic, the residual energy after leaving the BPSG film would depend on the path length traveled in the film. The energy loss /4/ is, therefore, a direct measure of the depth where the nuclear reaction took place. By obtaining the energy spectrum of the $\alpha$-particles, the depth distribution of B was obtained. The integrated area under the distribution curve was proportional to the total boron content of the film. The width of the curve yielded the thickness of the film.

Results and discussion

A set of ion-implanted boron-doped Si wafer samples were run. Data from these samples are shown in Table I. As can be seen from the table, an agreement of better than 5% is obtained with the ion-implanted dose.