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Nuclear Instruments and Methods in Physics Research B 237 (2005) 336–340
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Low energy electron induced X-ray emission spectrometry (LEXES) and secondary ion mass spectrometry (SIMS) sensitivity studies to ultra shallow arsenic implants

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Available online 20 July 2005

Abstract

CMOS device sensitivity to process variation is becoming increasingly important as devices are scaled down to smaller sizes. As a result, there is a growing demand for ion implantation and annealing tools to increase accuracy and repeatability. In parallel, there is also an increasing challenge on the metrology equipments to exhibit greater sensitivity to implant and annealing process variations.

In this work we will focus on studying metrology sensitivity to NMOS junctions formed with ultra shallow arsenic implants. For the sensitivity to energy variation, the arsenic is implanted at energies from 1800 eV to 2200 eV by steps of ±20 eV, ±50 eV, ±200 eV around arsenic 2 keV at 1×10^{15} ions/cm^2. To study the sensitivity to dose variation, a second set of wafers were implanted with arsenic at 2 keV with different doses ranging from 1×10^{14} to 2×10^{15} ions/cm^2.

Low energy electron induced X-ray emission spectrometry (LEXES) is used to monitor dose sensitivity before and after annealing, secondary ion mass spectrometry (SIMS) is used to monitor the dose and profile sensitivity after anneal. AR-XPS was also used to monitor the native oxide thickness before and after annealing, and the oxidation state of arsenic.

PACS: 42.62.Eh

Keywords: Arsenic; Ion implantation; Metrology; Low energy electron induced X-ray emission spectrometry; Secondary ion mass spectrometry; Angle resolved X-ray photoelectron spectroscopy

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0168-583X/$ - see front matter
doi:10.1016/j.nimb.2005.05.010

1. Introduction

In-line metrology sensitivity to process variation is becoming increasingly critical and challenging as the industry moves towards smaller technology nodes. As a result of this increasing need for accurate dose measurement of low energy implants, low energy electron induced X-ray emission spectrometry (LEXES) has been developed to allow for non destructive full wafer dose quantification. In an earlier work [1] we have reported a comparative study, based on implanted indium, between LEXES and secondary ion mass spectrometry (SIMS). In this paper we are reporting results on LEXES and SIMS sensitivity to very shallow arsenic implants. The biggest challenge is the ability of both techniques to accurately and precisely measure implanted dose of shallow arsenic before and after annealing. This challenge is mainly important due to the presence of relatively thick native oxide grown especially after anneal. The presence of thicker oxide on the surface is known to cause quantification issues when performing arsenic measurement with SIMS, for example, due to the very high secondary ion yield variation between oxide and silicon.

2. Experimental details

Two sets of 300 mm, ⟨1 0 0⟩, P type wafers (10–30 Ω/sq) have been implanted using applied materials quantum III™ and annealed using Applied Materials Radiance *Plus* Rapid thermal annealing chamber.

The first set of wafers was implanted with Arsenic at 2 keV to the following doses: 1×10^{14}, 3×10^{14}, 5×10^{14}, 9×10^{14}, 1×10^{15}, 1.1×10^{15}, 2×10^{15} ions/cm^2.

All the wafers in the second set of wafers were implanted at 1×10^{15} ions/cm^2 but at following energies: 1800 eV, 1950 eV, 1980 eV, 2000 eV, 2020 eV, 2050 eV and 2200 eV. All the wafers were then annealed at 1050 °C spike and to prevent arsenic from outgassing a 10% oxygen concentration in N_2 atmosphere is used. Angle resolved X-ray photo-electron spectroscopy (ARXPS) was also used to determine oxide thickness on the wafers before and after annealing.

For the purpose of this work both LEXES and SIMS have developed respective approaches to take into account native oxide thickness change after implant and anneal as follows:

1. LEXES have incorporated the presence of the oxide in the IntriX Model [2]. The IntriX Model is used to convert the X-ray intensity into absolute concentration. This model corrects for the energy loss by the electrons as they penetrate the matrix, the efficiency of X-ray production at any given depth, and the probability of the X-ray escaping the matrix from the depth of its production.

2. Special SIMS approach had to be developed to eliminate As measurement variations from SiO_2 to Si. This approach was successfully developed and verified by comparing two identical As implants at 10 keV to 1×10^{15} ions/cm^2 into Si with native oxide and through 120 Å grown oxide. The resulting data are presented in Fig. 1.

The doses measured for native oxide and 120 Å oxide samples are 1×10^{15} ions/cm^2 and 9.87×10^{14} ions/cm^2 respectively. One can see that the difference between detected doses does not exceed 1.3%, which is within the SIMS error estimated to be of ±1.5%. Also, there is no variation of either secondary ion yield of As or erosion rate between SiO_2 and Si. This allows high precision measurements on As implanted wafers with a various thickness of oxide. The details of this technique

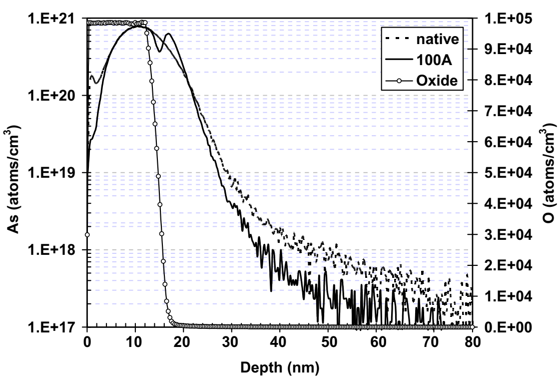

Fig. 1. SIMS profiles of 10 keV, 1×10^{15} ions/cm^2 arsenic implanted through native and 120 Å and SIMS profile of oxygen for oxide thickness measurement.