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Nuclear Instruments and Methods in Physics Research B 237 (2005) 318–323
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Implant process control: Going beyond particles and RS

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Available online 27 July 2005

Abstract

Ion Implant process control has changed considerably over the past 10 years. In the mid 1990s ion implant process control could easily be characterized as a daily dose monitor and particle check. However, as devices have shrunk and become faster, the sensitivity to process variations has increased, requiring a much more sophisticated process control strategy. Traditional test wafer based measurements now include periodic verification of implant angle accuracy, charge control system effectiveness, metals contamination, cross contamination and even ion gauge accuracy that are all known to contribute to process variations. In addition to more varied wafer based process verification methods, the introduction of networked data collection systems has now facilitated the ability to provide process monitoring of virtually every implant for every process recipe run. Automated systems can now monitor implant runs and flag possible out of control situations for review by process and equipment engineers, or depending on the severity of the fault, prevent further processing of material while the fault is investigated. Proper fault detection software and implant parameter databases provide process engineers with powerful tools to use for process optimization, interruption and fault elimination and correlation of tool operation parameters with device performance measurements. As fault detection systems are improved, the need for wafer based process control will decrease, although it is debatable that wafer based process control will ever be completely eliminated.

PACS: 61.72.Tt

Keywords: Ion implantation; Automatic process control; Fault detection; Energy analysis; Mass analysis; Charge control

1. Introduction

As the semiconductor industry has progressed from one technology node to the next, the demands of technology have facilitated the introduction of new classes of ion implantation equipment: high energy implanters which gained wide

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0168-583X/$ - see front matter
doi:10.1016/j.nimb.2005.05.006

acceptance in the mid 1990s, and low energy implant tools which started to arrive in many facilities in the late 1990s. Recently manufacturers have begun to introduce plasma tools and high tilt high current low energy tools. However, throughout this period of radical changes in process technology and the introduction of new tool platforms, changes in ion implant process control have lagged behind. In many factories, ion implant process control can often be characterized as little more than particle and sheet resistance (RS) monitors. However, as will be discussed in this paper, the demands of the technology and the demands of the marketplace have forced the leading semiconductor manufacturers to adopt a much more sophisticated process control strategy.

2. New demands on implant process control

As devices have shrunk and device speed and power consumption have increased, sources of process variation which caused negligible effects at older technology nodes now have become much more important. An example which resulted in significant changes in process control and manufacturing methods at Freescale Semiconductor's MOS13 facility is discussed in the following section.

2.1. Cross contamination in source drain extension implants

In a typical 0.5 μm CMOS fab of the early 1990s, it was often not necessary to dedicate ion implant tools to specific species: in many cases all tools were qualified to run all species. Process control strategies were put into place to prevent energetic cross contamination, such as boron fluoride co-implantation with phosphorous, but little attention was paid to the cross contamination effects of sputter deposition of dopants from beam stops and other surfaces struck by the ion beam, such as the process disk and dummy wafers.

During the development of high performance 130 nm node logic devices at MOS13, device engineering noticed large variations in n-channel (NMOS) device leakage. It was determined that phosphorous cross contamination at the low energy arsenic source drain (S/D) extension implant was the likely cause of the increased leakage, and a phosphorous segregation program was put into place to control the problem. Previous generations of logic devices were not affected by cross contamination, but within a single technology node this failure mode had suddenly become an acute problem.

An examination of secondary ion mass spectrometer (SIMS) profiles of a test wafer confirmed cross contamination was the source of the problem. SIMS profiles from an annealed test implant from a tool with heavy phosphorous contamination are shown in Fig. 1. The figure shows that phosphorus, which was initially peaked at the surface, diffused much deeper than the arsenic and pushed the p–n junction much deeper than the arsenic profile. Previous generations of NMOS devices had utilized higher energy implants and were much less sensitive to the effects of phosphorous contamination. A set of test wafers was implanted to quantify the effect of low energy phosphorus contamination on arsenic implants. Fig. 2 shows the effect of a 5% dose of 0.2 keV phosphorus on RS at various arsenic implant energies. Below 10 keV the effect of the phosphorus implant on RS increases dramatically. SIMS profiles showed that below 10 keV the phosphorous contaminant diffused beyond the arsenic and the junction depth was determined by the phosphorous profile. Based on these results, a new test implant, using a 4 keV 1.1×10^{15} atoms/cm^2 arsenic implant, is now used to qualify the low energy

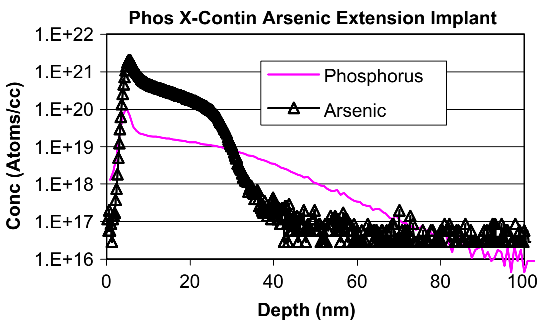

Fig. 1. Arsenic and phosphorus dopant profiles from an annealed 3 keV arsenic implant.