Metrology of 3D Transistors for La/Hf, Co, Ni dopant and thicknesses to sub-Angstrom equivalent thicknesses

Application Note

By Dr. Benjamin Stripe, Xiaolin Yang, Sylvia Lewis| Sigray. Inc

Abstract

We describe a new technique for non-destructive, quantitative measurements of next-generation transistors, such as FinFETs and Gate All Around (GAA) transistors. The Sigray AttoMap XRF microscope achieves ultrahigh sensitivity that is equivalent to sub-1 Angstrom measurements in spot sizes below 10 µm, which matches the needs of shrinking test pads. This approach provides ultra-high sensitivity at high throughput down to seconds for critical dopants and thin film elements such as La, Hf, Ni, Co, and has demonstrated <1% repeatability for 1-2 nm thicknesses measured within 2 minutes.

Introduction

Fast, non-destructive, and quantitative composi-tional analysis of trace level dopants and nano-structures is a major capability demand among the semiconductor and nanotechnology research community. The need for such analysis is driv-en by the rapid growth of 3D (non-planar) tran-sistors such as finFETs and new nanowire-based gate-all-around (GAA) structures. These 3D new geometries, dimensions, and compositions intro-duce major challenges for reliable quantitative re-sults using existing measurement approaches1-2. Furthermore, these systems must achieve the required high perfor-mance on smaller test struc-tures (e.g. 50 µm pads) of transistor arrays.

Current approaches: Nano-SIMS and TEM

Secondary Ion Mass (SIMS) spectrometry has been the workhorse analytical technique, in which a focused ion beam sputters the surface of a spec-imen, forming sec-ondary ions that are analyzed for composition. Howev-er, 3D transistors intro-duce substantial challenges in its use, including quantification inaccuracies because of sputtering rate variations, which can be due to factors such as non-planar structures1 and impurities in high-k gate hafnium dielectrics3. In addition, the acquisi-tion times required for accurate analysis is a bot-tleneck, typically taking ~30 minutes per test pad point.

To address these problems, Transmission elec-tron mi-croscopy (TEM) is used. TEM measures the transmission of electrons through a sample, and as a result, requires the preparation of an ultrathin lamella of <100 nm for a region-of-interest. TEM is labor-intensive and very low throughput, and the sample preparation and region-of-interest can re-move or destroy features of interest.

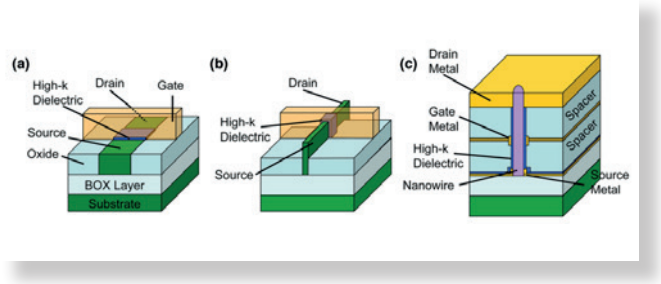

Figure 1. Semiconductor MOSFET designs: traditional 2D planar designs (shown in a) are now moving to complex 3D structures in 3D FinFETs (b) and proposed vertical nanowire designs (c), resulting in new analytical chal-lenges. A Moore and L Shi, "Emerging challenges and materials for thermal management of electronics." Materials Today 2014

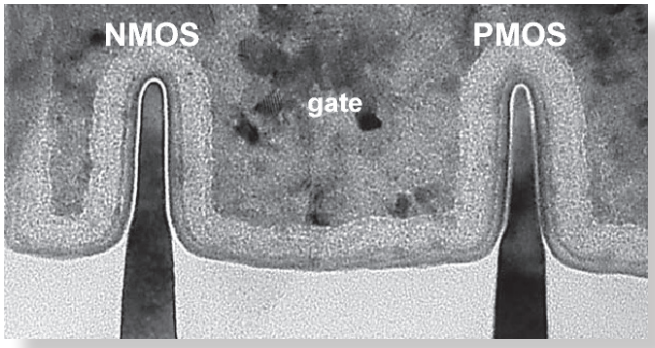

Figure 2. Current approaches to measure thin films are SIMS or TEM sectioning, both which are low-throughput and destructive. Shown above is a TEM image of a 16-nm finFET. D James, "Moore's Law Continues into the 1x-nm Era." 21st Itnl Conference on Ion Implanation Technology 2016.

A novel approach: Sigray AttoMap XRF Microscope

Sigray, through patented breakthroughs in x-ray source and x-ray optic technologies, has developed the AttoMap XRF microscope with sub-femtogram sensitivi-ties in a 10 µm spot. This technique has now been installed by two of the largest IDMs (integrated device manufacturers). With the AttoMap, relative concentra-tion can be provided with a high degree of accuracy without standards, and absolute concentration of high-k dielectrics of 1-2 nm thicknesses have been measured within 2 minutes with 1% repeatability.

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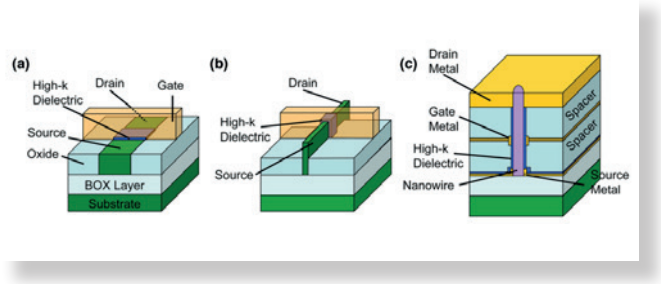

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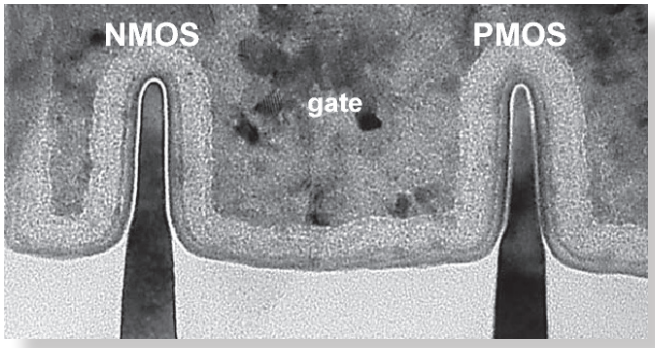

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