



Self Focusing SIMS: Probing thin film composition in very confined volumes



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ABSTRACT

The continued downscaling of micro and nanoelectronics devices has increased the importance of novel materials and their interfaces very strongly thereby necessitating the availability of adequate metrology and very tight process control as well. For instance, the introduction of materials like SiGe or III-V compounds leads to the need for the determination of the exact composition and thickness of the resulting thin films. Concurrent with this trend, one is faced with layer growth concepts such as aspect ratio trapping, which exploit the reduced dimensionality of the devices. As this leads to films with very different characteristics as compared to their blanket counterparts, characterization now has to be performed on thin films grown in very confined volumes (with dimensions ranging down to less than 10–20 nm) and standard analysis methods like X-Ray Photoelectron Spectroscopy, Secondary Ion Mass Spectrometry (SIMS) and Rutherford Backscattering Spectrometry, no longer seem applicable due to a lack of spatial resolution. On the other hand, techniques with appropriate spatial resolution like Atom Probe Tomography or Transmission Electron Microscopy are time consuming and suffer from a lack of sensitivity due to their highly localized analysis volume.

In this paper, a novel concept termed Self Focusing SIMS, is presented which overcomes the spatial resolution limitations of SIMS without sacrificing the sensitivity. The concept is based on determining the composition of a specific compound using cluster ions which contain the constituents of the compound. Their formation mechanism implies that all cluster constituents originate from the same collision cascade and are emitted in close proximity (<0.5 nm). As such, the composition information becomes confined (i.e. self focused) to the areas where all constituents are simultaneously present. The examples shown in this work are based on SiGe compounds and demonstrate that it becomes feasible to determine the composition of thin films in ultra narrow trenches (down to 20 nm in width) with good accuracy and sensitivity. Whereas for the case where the probing beam is focused to a dimension smaller than the width of the structure, the analyzed volume/data point becomes very small (< a few tens of nm³), the simultaneous detection of many atoms from the multiple structures in the Self Focusing SIMS approach, represents effectively a much larger volume providing the abundant sensitivity as the analyzed area is now increased up to 100 μm². On the other hand, the minimum depth probed (in each trench) is still governed by the depth resolution of SIMS, hence it is similar to the one encountered in SIMS experiments performed on blanket films. This can be as small as 1–2 nm/dec and is only limited by the energy of the sputter beam.

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1. Introduction

During the last years, new materials and new device architectures have been extensively investigated in the semiconductor

industries in order to boost the performances of next generation transistors [1]. In this context, strained-Ge (s-Ge) channel FET's (field-effect transistor's) have received high interest due to their excellent hole mobility [2,3] and the recently obtained results still encourage the semiconductor device industry to incorporate them in FinFET technology [4,5]. Similarly, III-V based FinFET's are considered as their potential n-FET counterpart. Although concepts exist to implement their growth on top of Strain Relaxed Buffer layers

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(SRB layers), selective area growth in narrow trenches becomes an interesting option when considering co-integration. An additional advantage of growth in confined volumes, is that this can provide unique phenomena such as defect trapping, cfr aspect ratio trapping [6], leading to enhanced material quality or meta-stable compounds as compared to blanket layer growth.

It is clear that for technology development as well as for production control the determination of the composition (and the thickness) of the films grown in such small volumes is of prime importance. Analytical techniques such as X-Ray Photoelectron Spectroscopy (XPS) and Rutherford Backscattering Spectroscopy (RBS) are normally used to determine the composition of such systems [7–9]. However, when the analysis has to be performed locally, i.e. when the thin films are confined in ultra narrow structures ($<1\ \mu\text{m}$), these methods lose their applicability as their spatial resolution (or beam spot size) is typically larger than a micron and not in line with the reduced dimensionality of the devices. Other analytical methods, like (analytical) Transmission Electron Microscopy (TEM) or Atom Probe Tomography (APT) [10,11], have sufficient spatial resolution and can be used to determine accurately the composition of thin films grown in confined volumes. However, these techniques suffer from a relatively low throughput (extensive and time consuming sample preparation) and potentially low sensitivity since the reduced analysis volume leads to poor signal intensities. Similarly to XPS and RBS, Secondary Ion Mass Spectrometry (SIMS) is also one technique suited for probing the composition of layers. For example, it has successfully been used to determine the Ge composition of SiGe thin films [12,13]. However, also here these studies are confined to blanket films or relatively large test pads (micron scale) because of the limited lateral resolution of the SIMS technique.

In this paper, we will demonstrate that by using the so called Self Focusing SIMS (referred to as SF-SIMS) concept, the problem of lateral resolution of the SIMS technique could be overcome and that the composition analysis of SiGe thin films in confined volumes could be performed. The solution presented in this work is based on the physics of the cluster emission process and therefore is independent from the specifications of the used SIMS instrument.

The performance of the SF-SIMS approach is assessed through comparative analysis of the Ge compositions in different SiGe or Ge layers (grown in devices with various lateral dimensions) using standard SIMS, APT, AES (Auger Electron Spectroscopy) and TEM/EDS (Transmission Electron Microscopy/Energy Dispersive X-Ray Spectroscopy). It will be shown that the SF-SIMS method enables an accurate measurement of the Ge content of layers in all cases (down to 20 nm trench widths) whereas severe limitations are encountered for the standard SIMS approach.

2. Materials and methods

The test structures used in this paper consist either of a SiGe film grown on top of Si, or of a strained Ge-film grown on top of a relaxed SiGe layer on Si. In the first case, the pattern consists of a 128 nm thick SiGe film (with a nominal Ge concentration of 24 at.%) epitaxially grown in structures on a Si substrate and surrounded by a $\text{Si}_3\text{N}_4/\text{SiO}_2$ bilayer stack, as schematically represented in Fig. 1a. The wafer contains repetitive blocks of around $2\ \text{mm} \times 2\ \text{mm}$ subdivided in sub-blocks of approximately $280\ \mu\text{m} \times 280\ \mu\text{m}$ with different sizes and spacings, the SiGe surface coverage being constant, e.g. 6.81%, in each sub-block [14]. Fig. 1b shows an optical image of the large block. Various shapes and dimensions of the SiGe structures are available in each sub-block, with dimensions of 10, 5, 1, 0.5, 0.3 and $0.2\ \mu\text{m}$, respectively. The SiGe structures could only be seen on the optical image for the largest sizes, like $10\ \mu\text{m} \times 10\ \mu\text{m}$. Fig. 1c provides a top view Secondary Electron Microscopy (SEM) image of the sub-blocks, on which the SiGe structures of smaller dimensions can be distinguished.

The second test wafer mimics much closer the real device geometry and contains even narrower structures as shown in Fig. 2. It is basically composed of SiGe layers (nominally 70 at.% Ge, 130 nm thick) grown in trenches on Si substrate. The trenches are surrounded by Shallow Trench Isolation (STI), i.e. SiO_2 , and capped with a thin, strained Ge layer (20 nm). The length of the trenches is kept constant ($10\ \mu\text{m}$) while various widths have been prepared, ranging from 20 to 500 nm. After deposition, the sample surface was chemically mechanically polished (CMP-process co-developed by IMEC/BASF using an acidic slurry containing Si particles [15]).

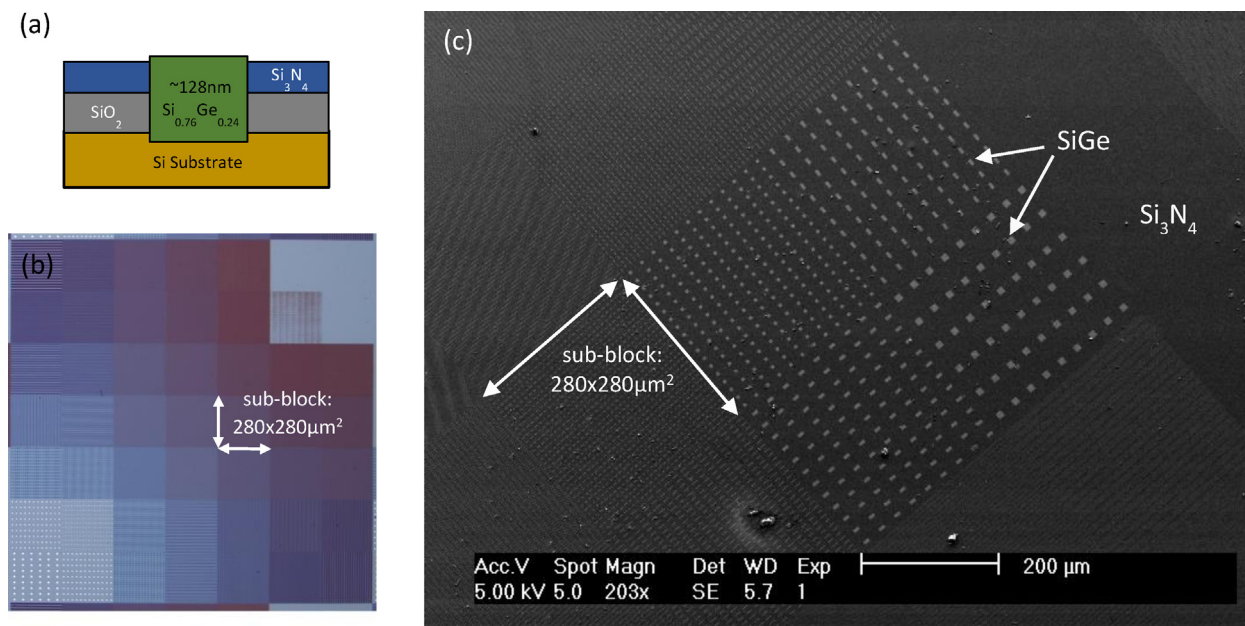


Fig. 1. (a) Schematic representation of the sample stack of the first test structure. (b) Top view optical image of one large block ($2\ \text{mm} \times 2\ \text{mm}$) containing sub-blocks of SiGe structures with various spacings and sizes. (c) Top view SEM image of various sub-blocks ($280\ \mu\text{m} \times 280\ \mu\text{m}$) of SiGe structures with various spacing and sizes. The SiGe surface coverage is constant in all sub-blocks and equal to 6.81%. Light and dark gray regions are the SiGe and Si_3N_4 layers, respectively.

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