IN-LINE AND NON-DESTRUCTIVE ANALYSIS OF EPITAXIAL $Si_{1-x-y}Ge_xC_y$ BY SPECTROSCOPIC ELLIPSOMETRY AND COMPARISON WITH OTHER ESTABLISHED TECHNIQUES

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The implementation of $Si_{1-x}Ge_x$ layers in active device structures is nowadays recognized as an efficient way to improve device characteristics. One example is the Heterojunction Bipolar Transistor (HBT) in the BiCMOS Technology, the core of which includes a $Si_{1-x}Ge_x$/Si heterostructure deposited by means of Reduced Pressure Chemical Vapor Deposition (RP-CVD). For future device generations (0.18 µm or below), the possible replacement of $Si_{1-x}Ge_x$ by $Si_{1-x-y}Ge_xC_y$ is currently under investigation. The implementation of C leads to reduced boron out diffusion. This device application requires very good control of layer thickness and composition. Unfortunately, most of the well-developed characterization methods such as RBS, SIMS, and Photo-luminescence measurements are unsuitable as production measurement tools. On the other hand, Spectroscopic Ellipsometry (SE) allows a fast, in-line and non-destructive analysis, including wafer-mapping facilities. Recently, we showed the suitability of SE to determine both Ge content and layer thickness of strained $Si_{1-x}Ge_x$ for Ge contents between 1 and 35% [1]. We use the ASET-F5 (Advanced Spectroscopic Ellipsometry Technology) system from KLA-TENCOR, which is a small-spot spectroscopic ellipsometer. The small spot (28x14 μm^2) size allows characterization of epitaxial layers grown in isolation structures. The small window size prevents RBS measurements. We describe the optical dispersion by means of the harmonic oscillator model, and obtained a clear correlation between the Ge content and $E_n(1)$, the resonant energy of the first oscillator, and n_{max}, the peak value of the real part of the refractive index (Fig. 1,2). In this way, SE allows the fine-tuning of selective and non-selective epitaxial growth processes with regard to growth rate, Ge incorporation and wafer uniformity.

In this paper, we use SE to extract the carbon content of epitaxial $Si_{1-x-y}Ge_xC_y$ layers with a fixed Ge content and for C contents between 0 and 0.7 %. The growth conditions are chosen in such a way that C incorporates fully substitutional. The Ge content is not influenced by the C incorporation, as confirmed by RBS and SIMS. Deposition of strained $Si_{1-x-y}Ge_xC_y$ with y = 0 gives a well-defined resonant energy $E_n(1)$ which corresponds to a certain Ge content (Fig. 1). The C incorporation (y > 0) reduces the strain in the epitaxial layer and leads to some modifications in the energetic band structure. This is reflected in $E_n(1)$, by a shift to higher energy values (Fig. 3). The results obtained so far, show a linear relationship between the shift in $E_n(1)$ and the carbon content as extracted by SIMS (Fig. 4). The obtained correlation allows the determination of the substitutional C content for samples with known Ge but unknown C contents.

Reference:
1. R. Loo et al., Journal of The Electrochemical Society 147 (2) pp 751-755 (2000)

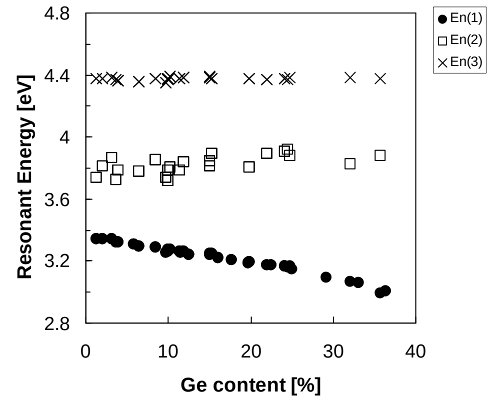

Fig. 1 Correlation between the Ge content and the resonant energies for the first three levels of the harmonic oscillator model

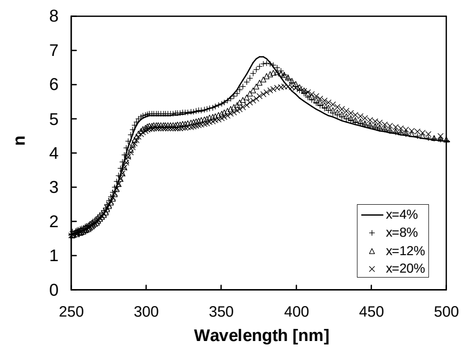

Fig. 2 $Si_{1-x}Ge_x$ Refractive Index dispersion for various concentrations of Ge.

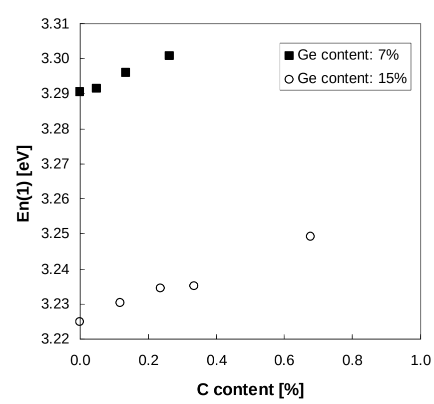

Fig. 3 Correlation between the resonant energy $E_n(1)$ as extracted from SE measurements and the C content measured by SIMS.

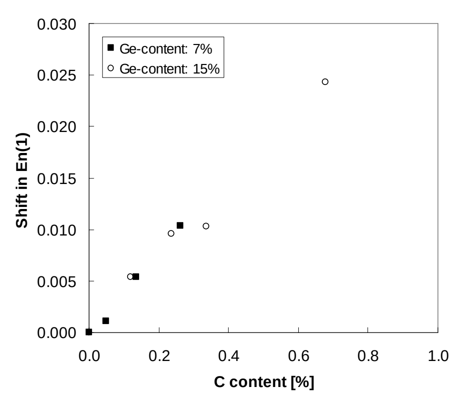

Fig. 4 Correlation between the shift in resonant $E_n(1)$ energy as extracted from SE measurements and the C content measured by SIMS.