Photoelectric Method For Non-Contact Characterization of SiGe

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Characterization of the epitaxial channel materials for sub 65nm transistors, such as strained epi silicon, presents one of the important metrology challenges today. The critical properties of the $Si_{1-x}Ge_x$ based devices, including switching speed and power dissipation, depend strongly on the amount of induced strain that is a function of germanium concentration (x). Another important parameter of the SiGe based structures is the thickness uniformity of the strained silicon layer. Strain and/or thickness can be measured by X-ray diffraction, X-ray reflectivity and Raman scattering techniques. All these analytical methods require substantial resources and are time consuming.

We have advanced a new non-contact photoelectric method for fast and accurate measurement of both critical parameters of material growth: germanium concentration x and thickness of top silicon epi layer. This method is based on a well-established small signal surface photo voltage technique [1]. The technique utilizes a frequency-modulated band-gap light of low intensity to generate electron-hole pairs in a near surface region. The capacitively coupled electrode measures a change in the surface potential caused by the minority carrier current. The measured photo-signal V_{spv} yields information about the charge in the space-charge region and near-surface minority carrier lifetime [2].

We have developed a new physical model and a measurement algorithm that extend the capabilities of the technique. The model takes into account the dependence of the measured surface photo-voltage to the surface potential value V_s. Surface potential depends on the doping concentration N_D and the intrinsic carrier concentration n_i that is a function of the material energy gap E_g [3]: $V_s \sim (kT/e)\ \ln(N_D/n_i(E_g))$. When applied to SiGe structure, the method allows determination the Ge content through correlation of the SiGe surface potential V_s to the alloy energy band gap Eg(x), which is proportional to Ge concentration x: $V_s = V_o + Eg(x)/e$, where $Eg(x)=Eg(Si)-Ax$. At certain conditions, the measured ac photo-voltage V_{spv} is proportional to the square root of the surface potential V_s and therefore to the germanium concentration $x^{1/2}$. The absolute value of x can be established through calibration to a reference wafer.

Another application of the developed technique is related to a thickness measurement of a thin strained silicon layer grown on top of SiGe layer. The principle of determination of the top layer thickness with ac-SPV method is similar to a thickness measurement of thin SOI structures [4]. For typical thickness of top silicon layer, less than 100nm, and resistivity greater than 0.1 Ohm cm, the surface depletion layer is larger than the silicon layer thickness. As a result, the whole silicon layer can be fully depleted. We achieve the required depletion level by non-contact photo-oxidation of the wafer surface and charging it with ionizing corona of appropriate polarity. When the top layer is the state of full depletion our method can reproducibly measure silicon layer thickness by correlating it to the effective depletion layer width.

In case of thick silicon layer (greater than maximum depletion layer depth) the technique allows calculation of the absolute value of the silicon layer doping density: $N_D \sim kT(\Phi/\omega V_{spv})^2$, where Φ is a probing light flux and ω is a light modulation frequency [2].

We present the results of the measurement of a set of SiGe samples with various germanium concentration and silicon layer thickness values. Figure 1 shows ac-SPV measurement of four $Si_{1-x}Ge_x$ wafers, with the range of x variation of about 13%. The measurements were done in a high frequency regime where low signal photo-voltage can be simply related to the surface potential, that results in a very good almost linear correlation of V_{spv}^2 to germanium content x.

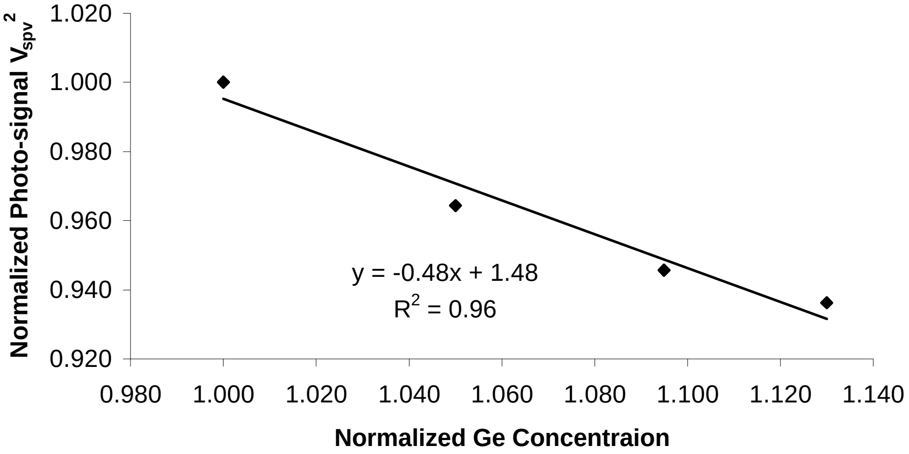

Figure 1. Correlation of normalized photo-signal to germanium concentration in SiGe layer

From Ge concentration dependence of measured photo-signal we calculate the value of the alloy characteristic material parameter - the coefficient (A) representing the energy gap dependence on Ge content. A good correlation of the calculated parameter value to the results available in the literature corroborates the accuracy of the new method.

References:

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