Optical Absorption of Si/SiGe Nano-structures

Günther Palfinger[a], Bernd Bitnar[a], Johannes Konle[b], Hans Sigg[a], Elisabeth Müller[a], Stefan Stutz[a], Hartmut Presting[b], Detlev Grützmacher[a]

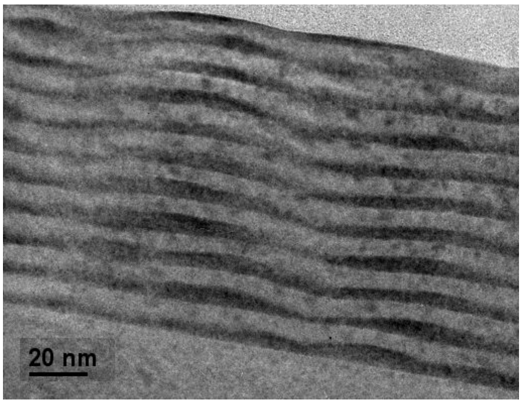
[a] Paul Scherrer Institut, 5232 Villigen, Switzerland
[b] DaimlerChrysler Research Center, 89081 Ulm, Germany

phone: +41-56-310 2580, fax: +41-56-310 2646, email: guenther.palfinger@psi.ch

Low band gap photocells can be applied for multi junction cells and in thermophotovoltaics. Until now, predominantly III/V materials, which are not compatible with the Si device technology, are used for these applications. In this paper we report on how the band gap of Si photocells can be reduced by SiGe nano-structures embedded in the space charge region. In principle, the nano-structures have the advantage that the band gap can be adjusted in the range between the Ge and the Si bandgap (0.65-1.12 eV at 300 K). Furthermore, SiGe nano-structures are expected to show a high absorption due to spatial confinement causing the spreading of the wave function of the holes in momentum space, which increases the probability of a transition without the aid of a phonon.

Samples with SiGe quantum wells and quantum dots were epitaxially grown with UHV-CVD and MBE [1, 2]. The MBE sample was grown using Sb as surfactant in order to achieve a high density of dots of small size. Fig. 1 shows two TEM micrographs of such Si/SiGe nano-structures in which the Ge rich regions are darker compared to Si. It can clearly be seen that the Ge rich islands in the MBE sample (Fig. 1a) are considerably smaller than the islands in the UHV-CVD sample (Fig. 1b).

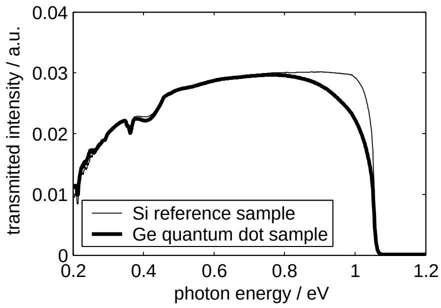
a)



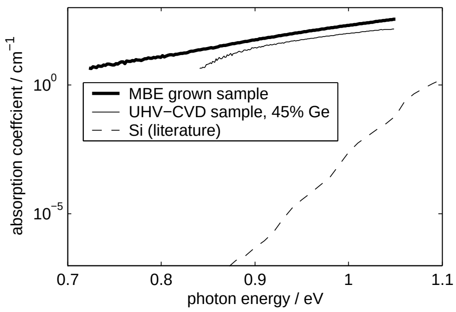
b)

Fig. 1: High resolution TEM micrographs of Si/SiGe nano-structures, a) as grown by UHV-CVD at 520 °C and b) as grown by MBE at 700 °C using Sb surfactant nucleated growth.

The absorption in the SiGe islands was measured by choosing a sample geometry, in which the light path experiences more than 200 total internal reflectedions [1]. To avoid problems with free carrier absorption, the samples were grown on highly resistive substrates. A Bruker Equinox 55 FTIR spectrometer was used, which allowed for measuring the transmission down to a photon energy of 0.2 eV. The transmission of samples with nano-structures was measured and compared to pure Si reference samples. As the measurements were not calibrated on an absolute scale, the data of different measurements have to be compared on a relative scale. The transmission of the sample with nano-structures was scaled to overlap with the transmission of the reference sample at low photon energies (see Fig. 2a). Investigations of the facet, surface roughness and absorbing water film on the surface did not yield any correlation to the absorption behaviour in the low photon energy region, leaving the reason for the drop at energies < 0.7 eV unknown. However, for our evaluation, only measurements for a photon energy > 0.7 eV is relevant, here the influence of the drop is negligible. The absorption of the SiGe nano-structures is obtained by dividing the absorption of the SiGe sample by the absorption of the reference sample. The absorption coefficient derived from the absorption and the effective thickness of the SiGe layers. Fig. 2b shows the absorption coefficient of two samples. The SiGe structures in the MBE grown sample are smaller and have a higher Ge concentration than those of the CVD grown sample, resulting in a higher absorption coefficient.



a)



b)

Fig. 2: a) The transmitted intensity of a Ge quantum dot sample grown by MBE (thick line) and the Si reference sample (thin line). b) Absorption coefficient as a function of the photon energy for SiGe structures grown by MBE (thick line) and by UHV-CVD (thin line).

In this work we improved the accuracy of the obtained absorption coefficient for photon energies in the range of 0.7 to 1.1 eV in comparison to former published results [1, 3] by using a more accurate spectrometer and more careful method of scaling, as well as by avoiding free carrier absorption. Although the absorption coefficient of the investigated SiGe nano-structures is several orders of magnitude higher than that of Si, further improvements, such as light trapping appear to be necessary to obtain photo-cells having a worthwhile quantum efficiency at photon energies below 1 eV.

References

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[3] B. Bitnar, G. Palfinger, D. Grützmacher, H. Sigg, E. Müller, S. Stutz, “Measurement of the Absorption Coefficient in SiGe Quantum Wells”, Quantsol 2003