Uniaxially-tensile strained ultra-thin silicon-on-insulator with up to 1.0% strain

R.L. Peterson[1], H. Yin[1], K.D. Hobart[2], T.S. Duffy[3] and J.C. Sturm[1]
1 Department of Electrical Engineering, E-Quad, Olden Street, Princeton University, Princeton, NJ 08544
2 Naval Research Laboratory, Washington, DC 20375
3 Department of Geosciences, Guyot Hall, Princeton University, Princeton, NJ 08544

Low uniaxial tensile strain of <0.04% has been recently reported to increase both PMOS and NMOS silicon-on-insulator (SOI) effective mobilities by ~15% [1], much more than that expected by comparable biaxial strain [2]. We have demonstrated uniaxial tensile strain in SOI of 0.6% using stress balance of a SiGe/Si bi-layer structure [3]. In this study, record uniaxial strain of 1.0% has been achieved by thinning the Si film in the bi-layer. This increased strain level should allow for even greater device performance enhancement.

SiGe and Si films are transferred to a BPSG (borophosphorosilicate glass)-coated Si wafer by a wafer bonding and Smart-Cut^{TM} layer transfer process described previously [4], forming 30nm $Si_{0.7}Ge_{0.3}$ / 10-25nm Si / BPSG. After transfer, the Si film remains relaxed and SiGe commensurately compressively strained. The SiGe/Si layers are patterned into islands with <100> edges. Upon high-temperature annealing BPSG viscosity decreases substantially and the SiGe expands laterally to relax its compressive strain, stretching the underlying Si film to create tensile strain. The bi-layer structure thus reaches an equilibrium state of stress balance [5]. Strain is measured by micro-Raman spectroscopy at 488 or 514nm [6].

For islands of edge length L, lateral relaxation occurs according to the time constant, $\tau \propto L^2$ [4]. Small square islands result in biaxially-symmetric strain, while rectangular islands maintain their initial strain in the long dimension (here, 150μm) but quickly expand in the short dimension (≤ 20μm), yielding uniaxial tensile Si strain. The net strain change is identical for the Si and SiGe films because of their coherent interface [5]. That the two layers move together is clearly demonstrated for 20μmx150μm islands of 30nm SiGe / 25nm Si / 200nm BPSG, before and after 30min at 800°C in nitrogen: $\Delta\varepsilon_{Si} \approx \Delta\varepsilon_{SiGe} = 0.75\%$.

To obtain larger uniaxial Si strain we use a thinner layer of Si: 30nm SiGe / 10nm Si / 5.5nm SiN_x / 1μm BPSG. SiN_x is added to suppress dopant out-diffusion from BPSG [5]. After 15min at 750°C, SiGe strain in the short-dimension direction changes from 1.2% to 0.2% (i.e., from full compressive strain to almost complete relaxation) in agreement with predicted SiGe strain of 0.2% based on stress balance. The resulting uniaxial tensile strain in the underlying 10nm Si layer is directly measured to be 1.0%, again confirming a coherent SiGe/Si interface. For stress balance of the same bi-layer, uniaxial Si strain is greater than biaxial Si strain (~0.7%) due to the long island dimension constraint, which causes all the expansion to take place in the short dimension.

1. B.M. Haugerud, et. al., Journal of Applied Physics, 94, 4102 (2003) 2. S. Takagi, et. al., IEDM Digest, Washington, DC (2003), pp.57-60 3. H. Yin, et. al., MRS Fall Meeting, Boston, MA (2003) 4. H. Yin, et. al., Journal of Applied Physics, 91, 9716 (2002) 5. H. Yin, et. al., IEDM Digest, Washington, DC (2003) 6. S.C. Jain, et. al., Physical Review B, 52, 6247 (1995).