**Strained Semiconductor Films** <u>Semiconductor Note 7, posted July 28, 2003</u>

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The strain in crystalline solid results from the relative displacement of atoms in the lattice. The strain creates proportional distortion of key material properties of semiconductor including energy gap and effective mass of an electron - effective mass of an electron in the strained region is reduced, hence, its mobility is increased. Consequently, creation of strain in the region of transistor in which mobility of electrons has an effect determining its performance will result in the faster switching transistor. Due to the performance enhancing properties, the lattice-mismatched semiconductor heterostructures containing strained films are rapidly growing in importance in semiconductor device technology.

To explain the concept of strained semiconductor films consider single crystal materials S and F featuring different lattice constants $a_s$ and $a_f$ (Fig.1a). If S is a substrate upon which F is formed by epitaxial deposition this lattice mismatch ($a_f$ ? $a_s$) will cause a build-up of the strain in the film as its thickness increases. Eventually, the strain energy will have to be completely or partially relieved by generation of dislocations at the interface (misfit dislocations in Fig.1b). At this point lattice constant of the film will relax toward the

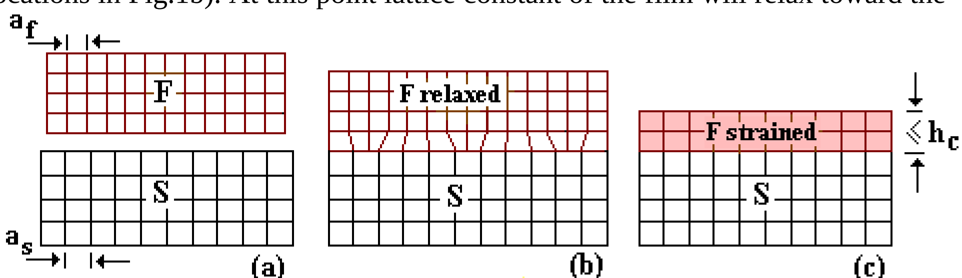


Fig. 1

unstrained value. However, if the film growth will be stopped below critical thickness $h_c$, i.e. in the thickness regime in which lattice mismatch is still accommodated by strain in the film (such film is called a pseudomorphic film) then, a defect-free, highly strained single-crystal F film will be formed on the substrate S (Fig.1c). Critical thickness $h_c$ decreases as the lattice mismatch f ($f = a_f - a_s/a_{avg}$) increases. In practical strained-layer heterostructures the lattice mismatch typically does not exceed 5 % and typical thickness of the film ranges from 1 to 20 nm.

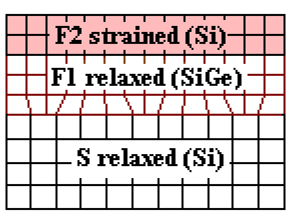


Fig. 2

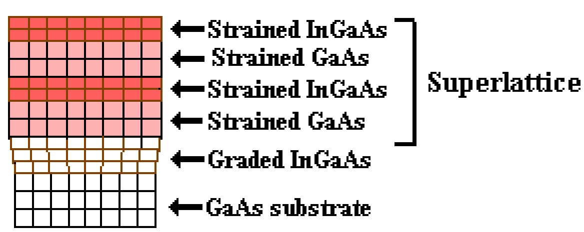


Fig. 3

As stated earlier strained films are used to enhance performance of both silicon- and GaAs-based transistors. Formation of the layer of strained silicon on silicon substrate requires a buffer layer of SiGe (Fig.2). Strained SiGe itself formed on Si substrate also finds applications in very high-frequency transistors manufacturing. In the case of GaAs-based devices strained films are incorporated in the device structure in the form of strained layer superlattices (SLS). The SLS structures display unusual properties that can be used to design high performance electronic (e.g. quantum well) and photonic (e.g. novel photodetectors and lasers) devices. As Fig. 3 shows SLS is a multilayer structure comprising of alternating epitaxial layers (formed on GaAs substrate) of two lattice mismatched materials each having a thickness below $h_c$ (often AlGaAs is used in conjunction with GaAs). The key to the fabrication of superlattice is very precise (atomic scale) control of chemical composition and thickness of the film. Both are possible using Molecular Beam Epitaxy (MBE).