Chapter 5

GaAs on Si by MBE

Epitaxial growth of GaAs on Si substrates has attracted a great deal of attention because of the promising possibility of combining the optoelectronic performance of III-V materials with Si integrated circuit technology.

In recent years, much attention has been paid to the good heteroepitaxial growth of GaAs on Si. Many attempts have been made to reduce the dislocation density, the residual stress and the antiphase domain in GaAs. Tilted Si (100) substrate, strained-layer superlattice (SLS), thermal cycle, postgrowth anneal and impurity doping are used for this purpose. In addition to these problems, the islands growth in the initial growth stage affects the quality of GaAs grown on Si. Although the origin of the island growth has not been clarified, plane defects produced when islands coalesce have been thought to affect the quality of GaAs grown on Si.

Heteroepitaxial GaAs on Si substrates is a very engaging material for the monolithic integration of optoelectronic and microelectronic devices. In spite of the formation of antiphase domains, 4.1% lattice mismatch, difference in thermal expansion coefficient, unintentional Si autodoping in the GaAs layer, and roughness of surface morphology. Laser diodes, solar cells, metal-semiconductor field-effect transistors (MESFET) and high-electron-mobility transistors (HEMT) have been fabricated on the GaAs/Si by metalorganic chemical vapor deposition (MOCVD) or the molecular beam epitaxy (MBE) technique. The difference of the lattice constants and the thermal expansion coefficients between GaAs and Si cause a high density of misfit and threading dislocations. The roughness of surface morphology of the GaAs/Si causes the nonuniformity and the undulation of the quantum well thickness. These problems affect device performance, namely, shorten device lifetime, increase threshold current density and decrease quantum efficiency.

Table 5.1 Some important data of Si and GaAs at 300 K [13].

	Si	GaAs
Lattice constant [Å]	5.431	5.6533
Bandgap [eV]	1.12	1.424
Band structure	indirect	direct
Intrinsic electron mobility [cm^2/V·s]	1500	8500
Intrinsic hole mobility [cm^2/V·s]	450	400
Thermal conductivity [W/cm·K]	1.5	0.46
Thermal expansion coefficient ($dL/L \cdot dT$) [K^{-1}]	2.6x10^{-6}	6.4x10^{-6}

The advantages of GaAs over Si from table 5.1 are the effectiveness optical property due to direct bandgap. The radiative recombination of AlGaAs can be varied using Al content variation from 0 to 45 % . Electron mobility in GaAs is larger than in Si, this effect high responsibility in the devices based on GaAs fabrication.

However, GaAs has lower thermal conductivity than Si for 3 times. Thus, the GaAs substrate that used as a basement while the devices fabrication must be thinned using lapping and/or chemical etching process for more effective heat transfer. The GaAs substrates are normally 300 μm thick for easily holding. But after the epitaxy process, more than half of the substrate is discarded. One question will then occurs : Why we waste this very expensive material ?

The well-known and cheaper material like Si could be a new trend to compromise GaAs-based optoelectronic and cheap, mechanical strong, Si substrate. But as hinted before, there are physically mismatches by an epitaxial growth of GaAs on Si.

The diamond structure in which Si crystallizes consists of two interpenetrating face-centered cubic sublattices. These sublattices differ from each other only in the spatial orientation of four tetrahedral bonds that connect each atom to its four nearest neighbors belonging to the other sublattice. There is no distinction between the two sublattices otherwise; both are occupied by the same atomic species. Contrast to the zinc-blende structure, in which atom the other by As atom. In a crystal without antiphase disorder the sublattice allocation is the same throughout the crystal. But if this allocation changes somewhere inside the crystal, as shown in figure 5.1 the interface between domains with opposite sublattice allocation forms a two-dimensional structural defect called an antiphase boundary. The domains themselves are called antiphase domains.

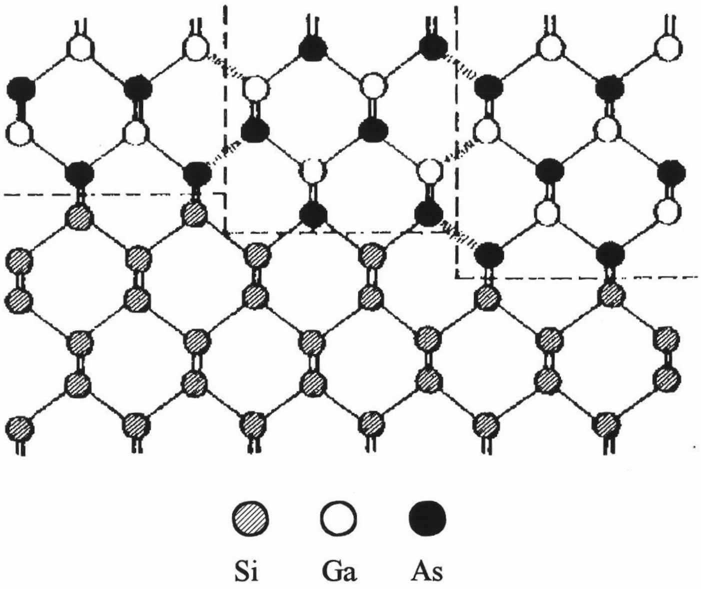

Figure 5.1 Antiphase boundary formation in the zinc-blende structure.

The antiphase boundaries are structural defects which may also be found in GaAs containing Ga-Ga and As-As bonds. These bonds represent electrically charged defects, strain in the epitaxial layers from antiphase domains in GaAs and roughness of Si surface at the initial growth stage. Normally, in any real (100) surface always exhibit single-steps as shown in figure 5.1. But when the step on a Si substrate surface is an even number of atomic layers high, the two sublattices in GaAs are in registry again then antiphase boundary will not occur at this step. It is found that on Si surface tilted by a few degrees from the (100) plane towards the (011) plane, most steps are two atoms high. The double step surface by misorientation substrate is then not only for growing GaAs-on-Si but also GaAs and others III-V compounds system.

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For the past several years, there were a large number of laboratories which are intensively working to solve these defect problems. Several novel techniques to reduce the defect density have been reported, e.g. use of Si initial buffer layer to prepare a very clean Si surface [14] and a Si interlayer that has been expected to block the dislocations [15]. Ideas to block the dislocation using a strained-layer superlattice such as InGaAs [16] and $(GaAs)_{1-x}(Si_2)_x$ [17-19] strained-layer superlattice have been investigated. Thermal cycling layers or so-call thermal strained superlattices (TSL) are inserted in the buffer growth and found to be effective in blocking dislocation propagation [20]. Studies on growth temperature are also reported for low-temperature GaAs-on-Si MBE [21]. This technique has been investigated and found to provide a short carrier lifetime which is applicable to an ultrafast GaAs-based photodetector. A new technique to enhance the diffusion length of Ga is presented by a low temperature MBE process which gives high-quality homoepitaxial GaAs [22]. This technique is called Migration-Enhanced Epitaxy (MEE). Recently, MEE became a regular process to grow initial layers of GaAs on Si.

Local growth of GaAs epitaxy is another novel technique to decrease the effect of the residual thermal stress. GaAs/AlGaAs heteroepitaxial layers have been grown on trenched Si substrates [23] and with the mesa release/deposition method [24], the behaviour of the devices showed, that the variation of residual thermal stress is related to the stripe width of the mesa-devices.