Chapter V
CONCLUSIONS

This work dealt with the study of the electrical and structural properties of Si-Si and Si-GaAs interfaces obtained by UHV bonding and layer transfer.

As asserted by the grain boundary theory and observed in earlier studies, the bonding process causes a quasi-continuum of states at the bonded interface, which yields a potential barrier and generation-recombination centers.

In the case of p-p and n-n interfaces the trap occupancy increases with applied voltage delaying the collapse of the potential barrier. Thus, the interface has a relatively high resistivity at low bias values acting like a rectifying element in blocking direction. The current is given by those carriers which have enough energy to overcome the grain boundary barrier. Recombination-generation mechanisms play a less important role in the case of unipolar interfaces. Due to the Fermi level pinning at the interface, only levels lying within a few kT away from the midgap can be charged using low and intermediate bias values, as revealed by DLTS measurements and numerical simulations. The calculated trap densities are relatively high for as-bonded interfaces. Similar values were determined by capacitance-voltage measurements performed in previous studies.

In the case of p-n interfaces the presence of interface states does not cause a distinctive potential barrier, but decreases the total depletion width. In order to relate the interface charges to the capacitance transient, the doping change at the interface had to be taken into account when deriving the capacitance formula of a p-n junction. It was found that the trap occupancy decreases with applied voltage as predicted in earlier works, in contrast to the unipolar case. The rectifying behaviour is affected by generation-recombination mechanisms which increase the reverse-bias current. The determination of the trap activation energies is cumbersome, especially in the case of p-n heterojunctions due to band discontinuities at the interface and the quasi-continuous character of the trap distribution. The current-voltage characteristics are in good agreement with numerical simulations performed with the software Tesca, based on a drift-diffusion model augmented to include interface states.

The surface activation before bonding was found to have a major influence on the bonding energy and the interface trap density. For Si surfaces a higher desorption temperature not only removes the hydrogen and the residual contaminants, but induces a higher ordering of the surface. In the case of GaAs surfaces, there is a precise temperature window for which the atomic hydrogen cleaning is efficient. It was found that flat, contamination-free surfaces result in interfaces with lower resistivity.

Upon annealing, the interface atoms rearrange in more favourable configurations, so that part of the strain introduced by the bonding process is released. Consequently, distorted bonds relax and a high number of dangling

bonds passivate reciprocally removing states from the bandgap. As a result, the overall electrical activity of the interfaces is decreased by high temperature annealing. In contrast to as-bonded interfaces, a regular dislocations network develops after annealing, accommodating the twist between the wafers (in the case of Si-Si interfaces) and the additional misfit (in the case of Si-GaAs interfaces) as confirmed by TEM investigations. Some irregularities of the dislocation lines are related to components accommodating the tilt related to the miscut and steps on the wafer surface. In Si-GaAs heterostructures, the annealing process causes element interdiffusion, changing the doping profile and shifting the electrically active interface into silicon.

The proposed layer transfer approach has been shown to work very well for different doping values, surface orientations and layer thicknesses in the case of Si layers transferred on Si substrates. The bonding energy depends strongly on the laser fluences used in order to activate the wafer surface. A photothermal excitation mechanism was identified to be responsible for hydrogen desorption from surfaces. The maximum fracture strength was attained for laser fluences which increase the surface temperature slightly below the melting point of Si. Numerical simulations showed that the heat pulse generated by the laser beam attenuates rapidly in Si. However, for high energies and small depths corresponding to the implantation range the damping is not high enough to avoid blistering. Therefore, the blistering onset tends to limit the laser fluence first, before surface deterioration by melting sets in.

A high temperature annealing step performed in hydrogen atmosphere flattens the transferred layer, removes the implantation induced damage and restores the electrical properties. The only surviving defects observed by TEM consist of nanovoids situated near the end of the implantation range, originating from platelets developed during the ripening process.

An important step towards extending the proposed approach to dissimilar materials has been made by transferring ultra-thin, single-crystalline GaAs layers on Si substrates. In spite of the presence of a thin oxide between the device and the handle, the interface resistivity was very low allowing high current throughput.