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Delta-Doping of Si on GaAs Vicinal Surfaces and Its Possibility of Wirelike Incorporation in Metalorganic Vapor Phase Epitaxial Growth

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1.Introduction

An ultimate control in crystal growth is the control of incorporation site of growth species on the surfaces. One of the approach for such purpose is to utilize atomic steps with fairly regular spacings on vicinal surfaces, as demonstrated by successful formation of fractional layer superlattices[1]. This kind of approach is also proposed to realize doping quantum wires(DQWs) [2] where dopant atoms are selectively incorporated along atomic step edges. Daweritz and co-workers have attempted and reported such wirelike incorporation of Si in GaAs by MBE[3]. It is also attracting for metalorganic vapor phase epitaxy (MOVPE) and is more interesting since spontaneous formation of the multiatomic steps plays an important role during MOVPE growth of GaAs on vicinal surfaces[4]. If one could combine multiatomic steps and wirelike incorporation of the dopants, DQWs with sufficiently large separations can be expected. Here we report on the delta-doping of Si in GaAs vicinal and singular surfaces in MOVPE growth and explored the possibility of selective incorporation of Si along atomic steps.

2.Experimental

The growth was carried out in a low-pressure MOVPE system with working pressure of 0.1atm. We used triethylgallium (TEGa), triethylaluminium (TEAl), and arsine (AsH_3) as source materials and monosilane (SiH_4) as a dopant. Substrates were singular and vicinal semi-insulating and n^+ (001)GaAs. The misorientation angle α was 2.0° and 5.0° toward the[$\bar{1}$10] direction. The layer sequence and the sample structure is schematically shown in Fig.1. Following a GaAs buffer layer, an $(AlAs)_3/(GaAs)_3$ superlattice buffer layer was grown at 600℃ in order to form monoatomic steps. Next, after the growth of undoped GaAs layer, where the multiatomic steps were formed on the surface, Si delta-doping layer was formed by supplying SiH_4 under arsine atmosphere without TEGa. The temperature during delta-doping was 600℃, and the doping times t_d were changed from 10sec to 1000sec. SiH_4 partial pressure was kept at 1.25×10^{-7}atm. Finally, 500nm undoped GaAs layer was grown as a cap layer at 550℃.

Atomic force microscopy (AFM) was used to investigate the surface morphology before and after the delta-doping. For the characterization of electrical properties, Hall-bar patterns were defined on semi-insulating substrates with conventional photolithography, wet chemical etching and lift-off technique. The channels were defined so that they were across ([$\bar{1}$10] direction) and along ([110] direction) the atomic steps. Schottky contact of aluminium was also formed on n^+ substrates for capacitance-voltage (C-V) characterization.

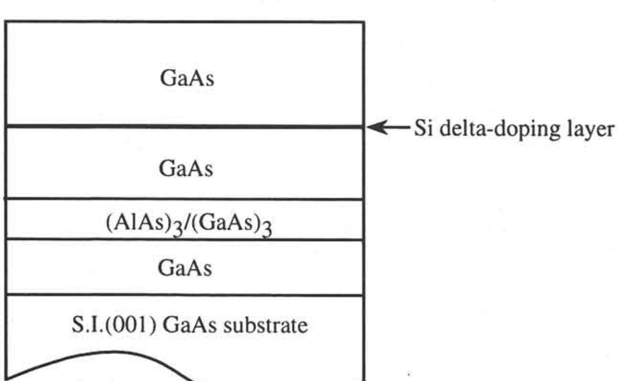

Fig.1 Schematic illustration of the sample structure

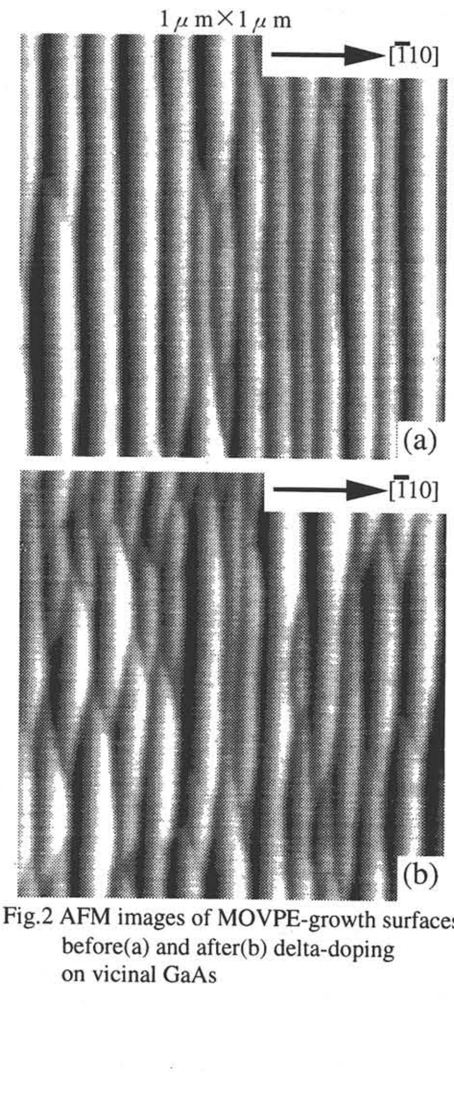

Fig.2 AFM images of MOVPE-growth surfaces before(a) and after(b) delta-doping on vicinal GaAs

3. Results and Discussion

Figures 2(a) and 2(b) show AFM images of vicinal GaAs surfaces of before(a) and after(b) the delta-doping layer, respectively. Here the substrate misorientation angle α was 2.0° and the doping-time t_d was 100sec, which corresponds to the Si doping concentration of $2.3\times10^{12}cm^{-2}$ for this surface. Multiatomic steps are formed for both surfaces. The average period the average height of multiatomic steps were measured to be 73.8nm and 1.35nm for surface(a) and 70.0nm and 1.23nm for surface(b), respectively.

Figures 3(a)-(c) shows a carrier profile of the samples of t_d=1000sec measured by C-V method at 300K. The FWHM of the peak and sheet electron concentration Ns are calculated from each profile and shown in each figure. The FWHM in each sample is comparable to the values reported by Schubert et al.[5] with similar doping concentration, indicating successful formation of delta-doping layer. One slso note that the Ns is larger in misoriented substrates, as will be discussed later.

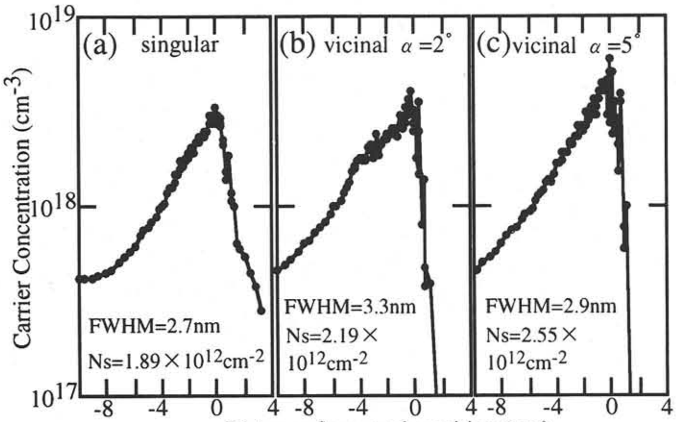

Fig.3 C-V profiles of Si delta-doped samples (300K)

Figures 4(a) and 4(b) show Hall electron concentration Ns^{α} for samples with different doping time, plotted as a function of the misorientation angle α. Here the measurement temparature was 300K and 1.8K for (a) and (b), respectively. The direction of the channel of the Hall-bar is in the [110]-direction so that the channels are along the steps for misoriented substrates, although the results are very simular for samples with [$\bar{1}$10] channel directions. With all some scattering in the data,we can reasonably say that Ns^{α} is higher in vicinal substrates than in singular substrates, and larger for larger misorientation angle α. This tendency is in consistent with our results on uniformly doped vicinal substrates, and results on C-V characterization in delta-doped samples described above.

In addition to the step-induced enhancement of Ns^{α} in misoriented substrates, Ns seems to be larger for shorter doping times. Such behavior is more clearly seen in inset of Figures 4(a) and (b), where normalized sheet carrier concentration Ns^{α}/Ns^{0} is plotted as a function of α for each doping times.

These results indicate that the incorporation of Si into GaAs is enhanced by the steps and that the doping density is higher at the multiatomic step edges than terrace regions. This effect is particularly importamt at the initial stage of delta-doping where the surface coverage of Si is sufficiently low. Therefore, we can expect the wirelike incorporation of Si in vicinal surfaces and also DQWs by further optimization of the growth conditions.

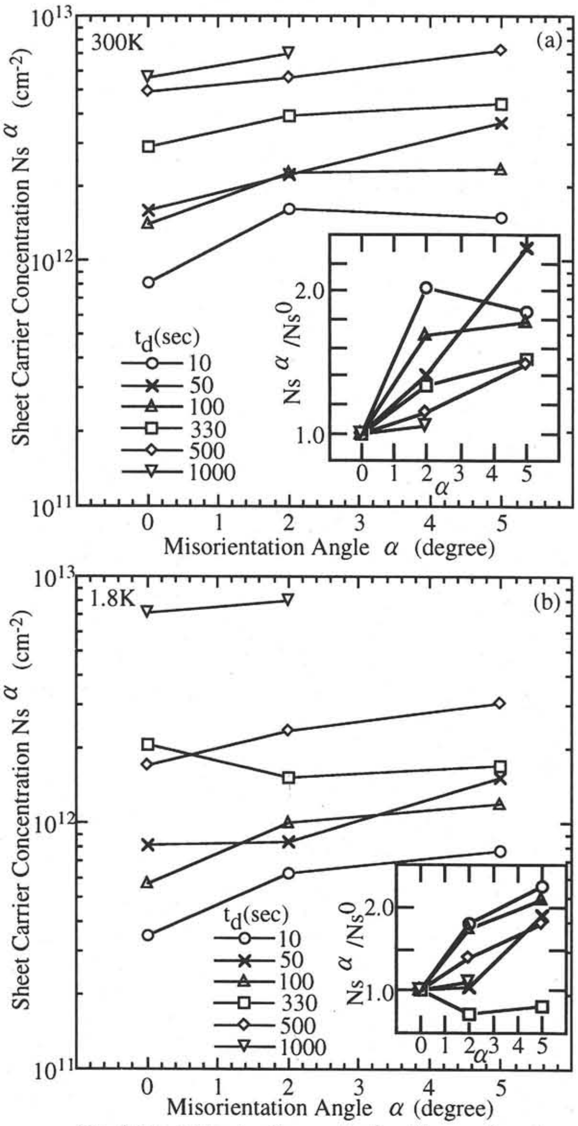

Fig.4 Sheet Carrier Concentration Ns as a function of misorientation angle α

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