Chapter 6

Selective growth of GaAs on Si by MBE

A shadow mask technique for local epitaxy, which is presented in this dissertation, has been successfully employed for growing mesa structures of Si on Si substrates [25,26]. The shadow masks consist of oxide/nitride sandwiches on a silicon substrate. After patterning the nitride and wet chemical etching of the oxide underneath, cantilevers of patterned nitride act as shadow masks.

6.1 Preparation of Shadow Masks on Si Substrates

Si(100) of nominally zero miscut and vicinal Si(100) substrates have been used to compare the structure morphology after MBE process. The vicinal Si wafers are 1.7° off the (100)-orientation. After a RCA cleaning process [27], a thermal oxidation process was used to grow SiO_2 up to 1 μm. In a LPCVD process, a 100 nm thick Si_3N_4 layer is deposited at T=700 °C upon the oxide layer. Lithography and reactive ion etching (RIE) processes were used for patterning the nitride film. After cleaning for the remaining resist, the oxide layer under the patterned nitride was carefully etched with buffered HF until reaching the Si surface. With this last etching step the Si substrate with the shadow masks on top of it is ready for MBE processing. Figure 6.1 shows diagrams of the shadow mask process including an idea of local epitaxy of GaAs by MBE grown on Si through the shadow masks.

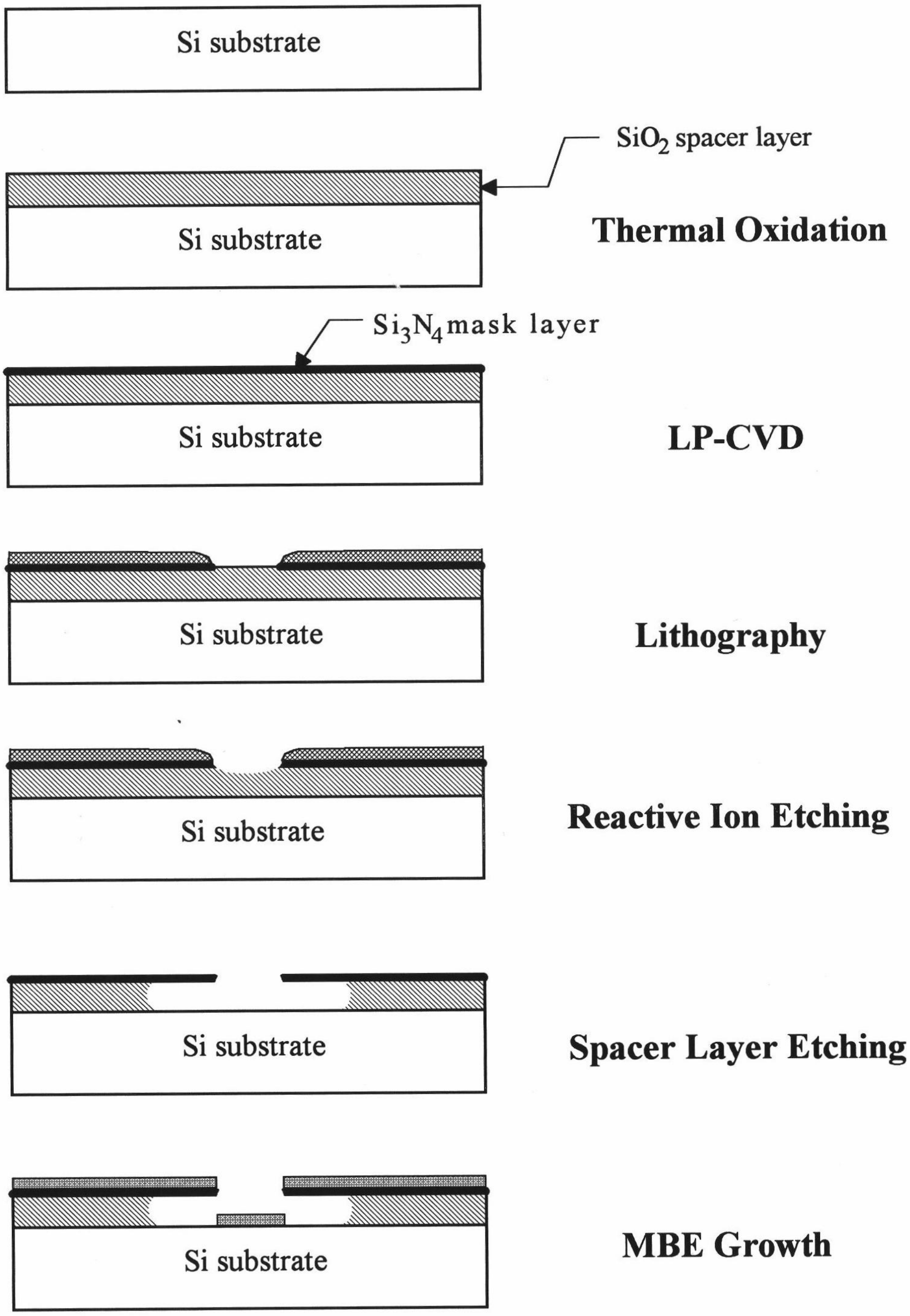


Figure 6.1 Processing of the shadow mask and GaAs deposition.

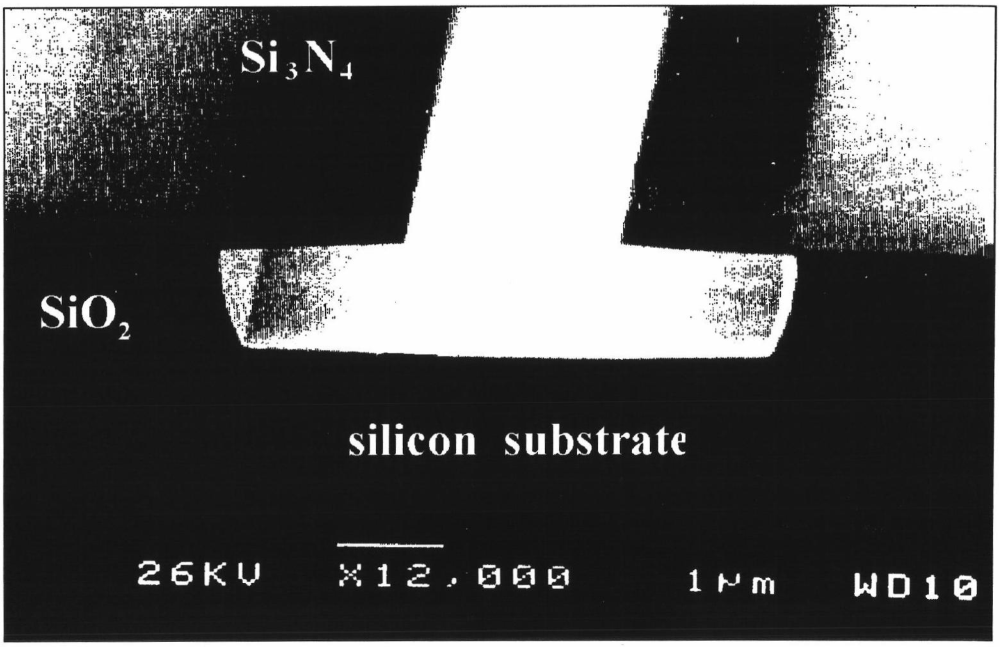


Figure 6.2 SEM picture of SiO_2/Si_3N_4 shadow mask on Si substrate.

6.2 Growing of GaAs by Shadow Masks

Before loading the wafers into the growth chamber, the wafers were heated in a preparation chamber at 1000 °C for 25 minutes to desorb the native oxide on the Si surface in the shadow mask windows. Table 6.1 shows a listing of the wafers that were used in the experiments. The sample #9562 is used for reference in comparing an epitaxial surface with those of the local epitaxial deposition.

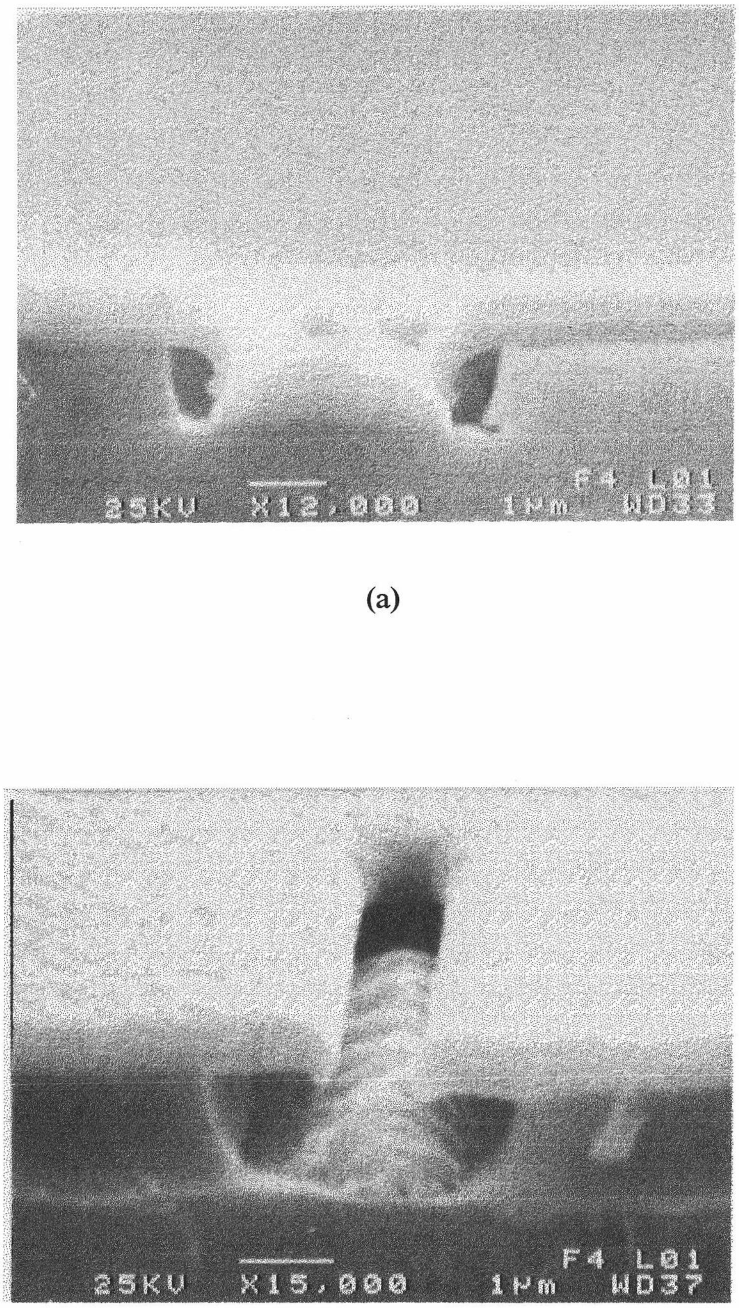
After the growth processes, all samples were cooled down under As_4 flux with the rate of 20 °C/min. Scanning electron microscopy (SEM) was used to examine the surface morphology of the local epitaxy.

Table 6.1 List of samples for the experiment.

Sample #	Description	Process sequence	Temperature (°C)
9562	Si (100) without shadow mask	MEE	200
		MBE	450
9581	Si (100) with shadow mask	MEE	200
		MBE	450
		MBE	520
9594	Si (100) with shadow mask	MBE	400
9613	Vicinal Si (100) with shadow mask	MEE	250
		in-situ annealing	400
9614	Vicinal Si (100) with shadow mask	MEE	250
		in-situ annealing	400
		MBE	400

Figure 6.3(a) and (b) are cross sectional SEM pictures which show the effect of different thermal expansion coefficient between the GaAs film and Si_3N_4 cantilevers [28]. It is noted that the bending of shadow masks strongly appears when the growth temperature was higher than 450 °C.

Another defect that always occurs in GaAs epitaxy on Si is an antiphase domain. Misorientated wafers seem to be appropriate to prepare double step surfaces and this significantly reduces the propagation of antiphase domain [17].



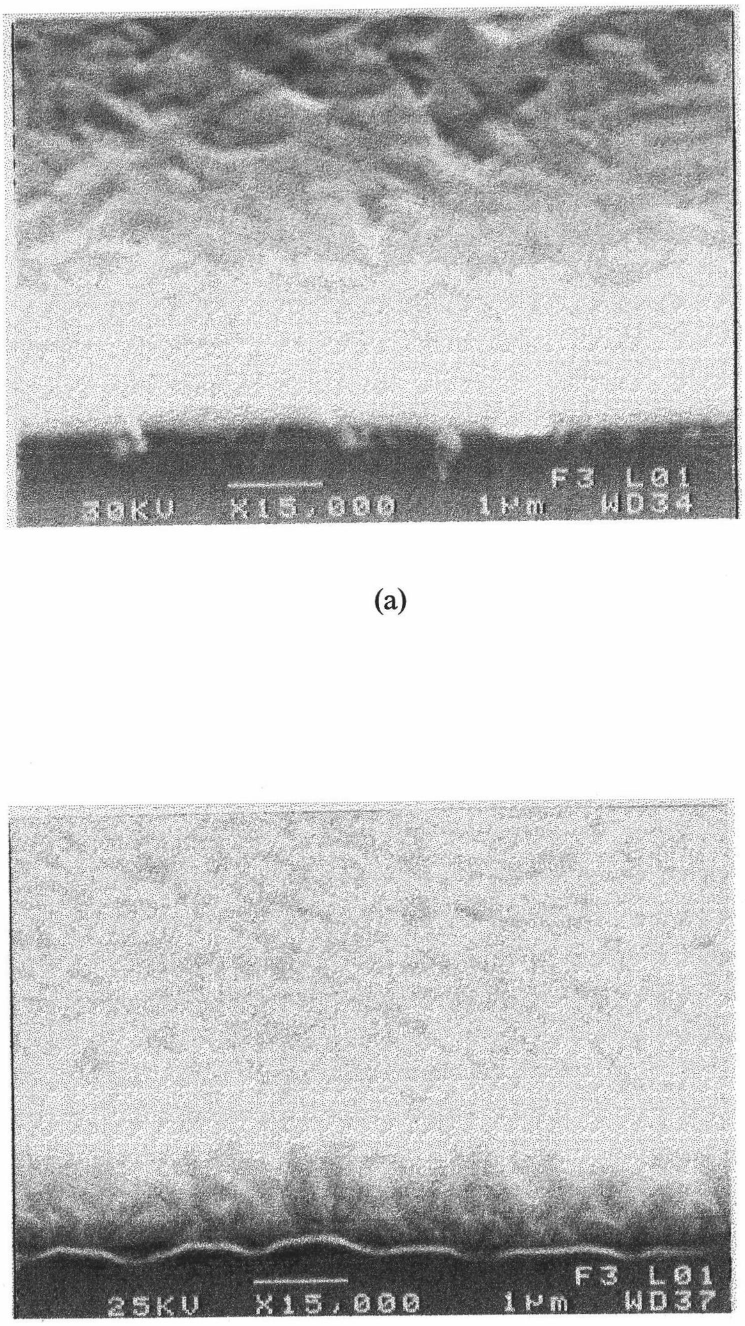
(a)

(b)

Figure 6.3 Effect of growth temperature on mask bending

(a) Sample #9581

(b) Sample #9594



(a)

(b)

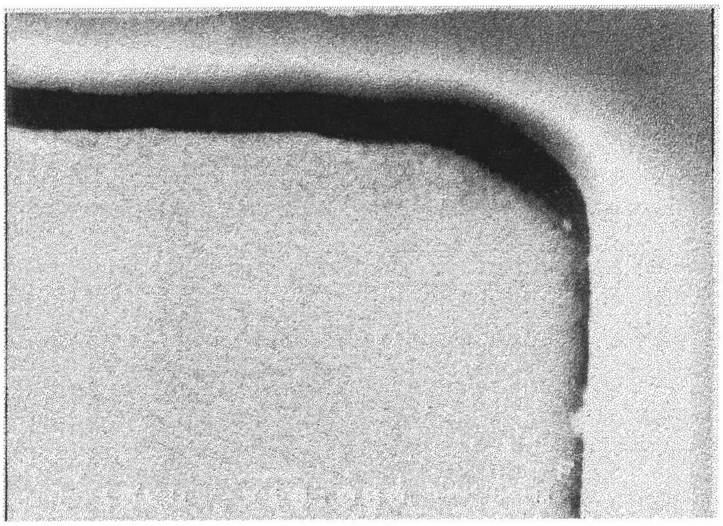
Figure 6.4 Comparing the effect of substrate misorientation

(a) Sample #9562

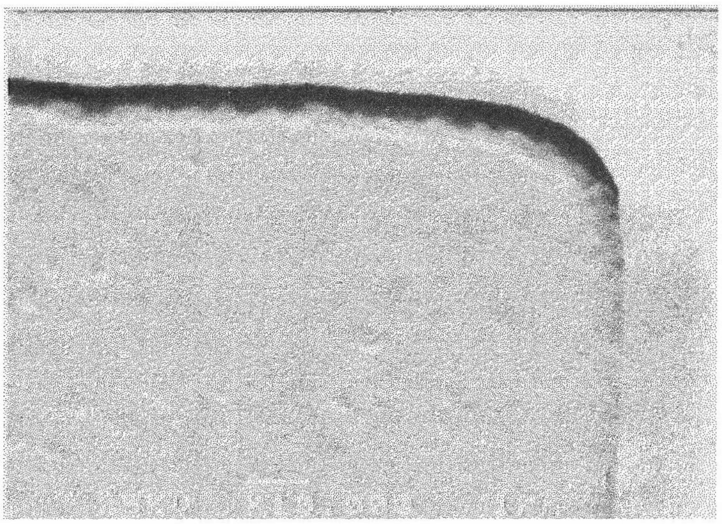
(b) Sample #9614

Figure 6.4(a) and (b) compare the surface morphology of epitaxial layers on an *on-axis* Si(100) substrate and a *vicinal* Si(100) substrate, respectively, under nearly identical growth conditions. In Figure 6.4(b) a portion of a rectangular shaped (200x200 μm^2) locally grown mesa island on sample #9614 is shown. This is a relatively large area local epitaxy and one can assume it to be of the same growth condition as for an overall grown surface. Nevertheless the local grown sample shows a higher quality for the epitaxial process. Thus the SEM pictures confirm that misorientation wafers provide a better crystal quality.

Figure 6.5(a) and 6.5(b) show the epitaxial surface morphology of sample #9613 and #9614, which are grown on vicinal Si substrates. The MEE technique in these experiments was done at 250 °C. Arsenic and gallium shutters were opened for 1 second consecutively with 1 second waiting time before each opening. This shutter-time schedule may not be optimized. Arsenic may not entirely cover the growth windows as complete monolayers which are necessary for perfect crystal growth. For this reason islands are formed by gallium. This effect continues and transfers to the surface of the epitaxial layers as can be seen for sample #9614.



(a)



(b)

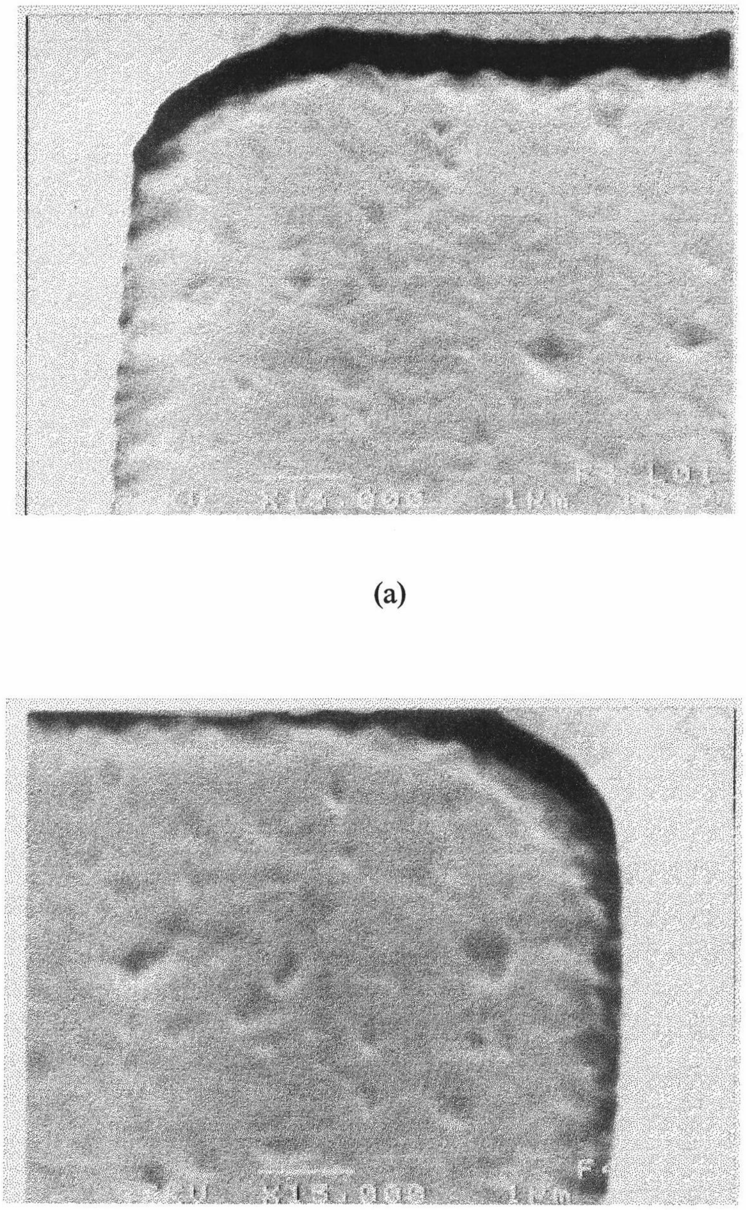
Figure 6.5 Surface morphology of epitaxy

(a) after MEE and annealing at 400 °C (sample #9613)

(b) continuing growth with normal MBE at 400 °C (sample #9614)

The size of the local epitaxy is also an important point to be cautiously considered. Figure 6.6 demonstrates the effect of local epitaxy size on the surface morphology. All of these structures were grown on sample #9614. From the observation, pin-hole density are all the same due to the sizes that used in this experiment are large comparing with the molecular step length on the growing surface.

However, for window sizes smaller than 10x10 μm^2, the pin-hole absolute number is dramatically decreased. It means that for the optimized growth conditions, small mesa structures grown by using shadow mask technique could be less in number of defects while without any mesa sidewall etched-damages.



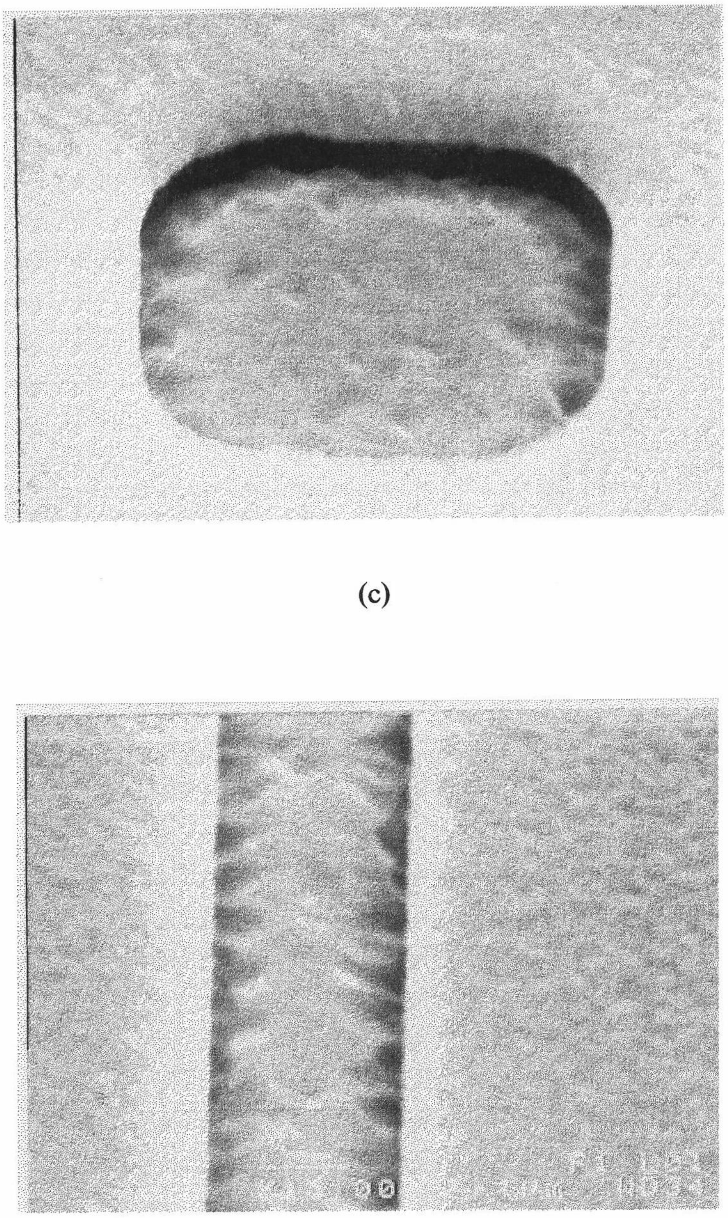
(a)

(b)

Figure 6.6 Surface morphology of different local epitaxial structures (sample #9614)

(a) 200x200 μm^2

(b) 10x10 μm^2



(c)

(d)

Figure 6.6 (continued)

(c) 5x5 μm^2

(d) line of 2 μm width