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Tunnels in Semiconductor Epitaxy

On (100) surfaces of III-V or II-VI compounds, tunnels or grooves can be grown over oxide or Mo stripes, the axes of which are in one of the two orthogonal $\langle 110 \rangle$ directions on the surface. One $\langle 110 \rangle$ direction produces grooves and the other, tunnels. By switching from n- to p-type layers at frequent intervals during growth, the mechanism can be elucidated.

It is well known that in the vapor phase epitaxy (VPE) of III-V and II-VI compounds there can be a considerable difference between the growth rates in the $\langle 111 \rangle_A$ and $\langle 111 \rangle_B$ directions [1]. This communication describes a method using this effect to produce interesting and potentially useful structures such as ink jet nozzles, gratings, etc.

The VPE of GaAs was carried out in a reactor with multiple source chambers and a revolving substrate holder that allowed the rapid shifting of the substrates from one chamber position to another [2]. This type of reactor is not necessary for the structural effects in the epitaxial layer. It is, however, helpful in elucidating the growth habit because of the ability it provides for switching from n- to p-type source chambers at regular intervals and then staining the cleaved edges of the deposited structure.

The GaAs was deposited onto the substrates at 750°C by passing a mixture of HCl and H₂ over chunks of the GaAs held at 850°C. The substrates were GaAs wafers oriented nominally 3° off a (100) plane toward a (110) plane. The substrates were first polished chemically with bromine in methanol and then coated with 200 nm of SiO₂ or Al₂O₃. Narrow parallel stripes were patterned into the oxide films using photoresist. The axes of the stripes were in one of the two orthogonal $\langle 110 \rangle$ directions in the (100) plane.

While the growth mechanism for tunnels and grooves is not yet well established, a tentative and simple explanation follows. If slow-growing (111) planes are adja-

cent to the edges of the stripes, V-grooves are formed over the stripes, whereas if fast-growing (111) planes are adjacent to the stripes, tunnels are formed. This is illustrated for two samples from the same run in Figs. 1(a) and (b), respectively. In these figures the changes from n- to p-type layers occurred every four minutes, and the edges were cleaved and stained. It is also possible to interpret the V-groove formation as resulting from fast growth of the $\langle \bar{1}\bar{1}2 \rangle$ and $\langle 11\bar{2} \rangle$ directions in the (111) and $(\bar{1}\bar{1}1)$ planes, respectively. Obviously, more work is needed to establish the exact growth mechanisms involved.

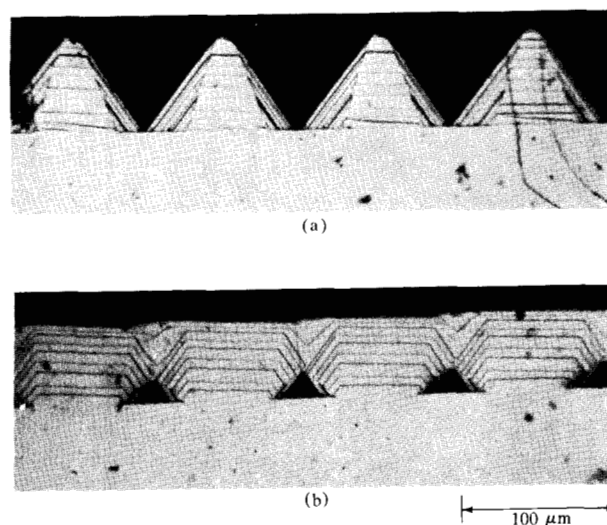


Figure 1 (a) Grooves and (b) tunnels deposited on two GaAs samples.

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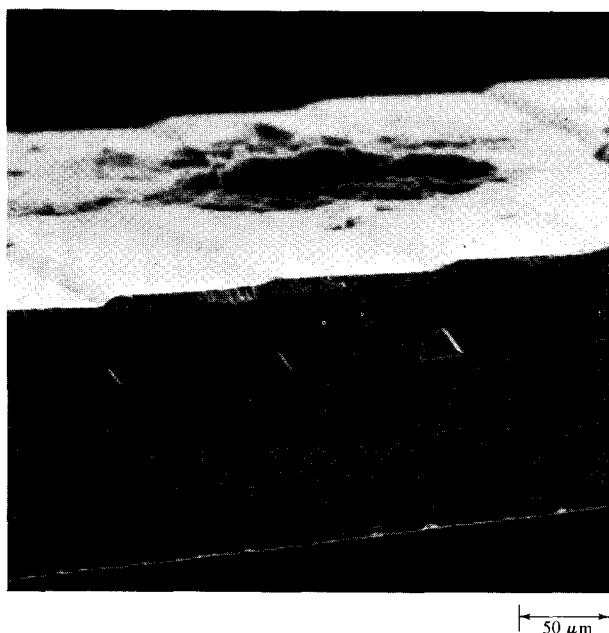


Figure 2 Scanning electron micrograph of a bar cleaved from the sample shown in Fig. 1(b).

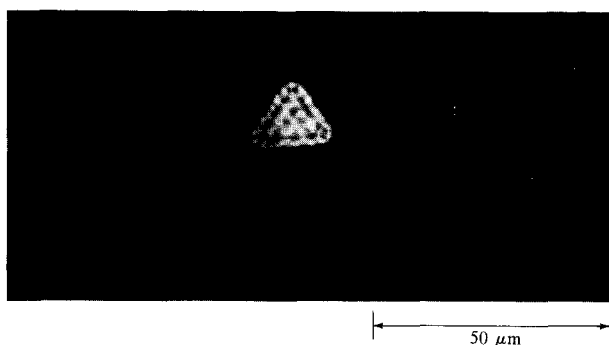


Figure 3 Emanating light from the cleaved edge of a tunnel structure from the wafer shown in Fig. 1(b).

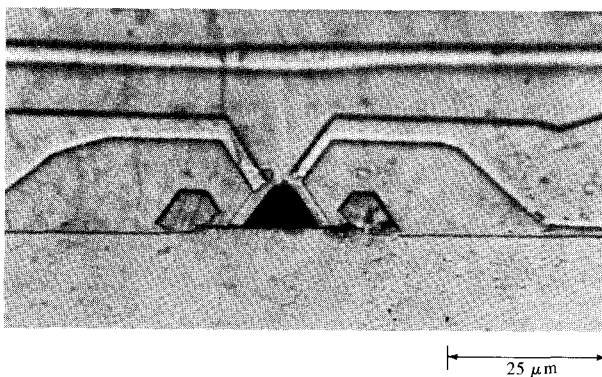


Figure 4 Cleaved and stained edge of a tunnel structure, showing the preferential nucleation at the edge of the oxide stripe.

In the case of tunnel growth, increasing the width of the oxide stripe increased the resulting bore of the tunnel; however, longer growth periods were then required to close the tunnel "roof." In these preliminary experiments, no serious effort was made to maintain a constant growth rate during the run.

Figure 2 shows a scanning electron micrograph of a tunnel array from the sample shown in Fig. 1(b). Here, the cleaved edge was not stained; however, the junctions are still faintly visible because of secondary emission of electrons from the p-type layers. Figure 3 shows a cleaved edge of a 0.9-mm-wide bar structure taken from the same wafer shown in Fig. 1(b). In this case, collimated white light is used to illuminate the edge of the bar and the figure shows the emanating light. The bright spots seen in the figure actually show a waveguide effect and are of different colors. (These can be photographed using color film.)

There are indications that at least part of the time nucleation occurs preferentially at the edge of the oxide stripes; see Fig. 4, which shows a cleaved and stained edge of a structure obtained where the change from n- to p-type layers occurred every eight minutes.

Tunnels have also been grown on GaP and over narrow oxide stripes in a $\langle 110 \rangle$ direction on a (100) surface of a silicon wafer. The results of these investigations will be published at a later date. The II-VI compounds also exhibit the preferential growth habit; *e.g.*, ZnSe grooved layers have been grown on (100) GaAs substrates.

It has recently been found that depositing GaAs layers do not nucleate on Mo; therefore, Mo stripes can be substituted for SiO_2 or Al_2O_3 to achieve tunnels or grooves. In addition, Mo is inert in halogen chemical vapor deposition reactions [3].

An empirical method for choosing the $\langle 110 \rangle$ direction on the (100) surface has been devised. A GaAs wafer with an oxide film on the polished surface is immersed in a 3:1:1 solution of $\text{H}_2\text{O}:\text{H}_2\text{O}_2:\text{NH}_4\text{OH}$ for approximately three minutes. Wherever a pinhole occurs in the oxide, an etch pit with an elongated outline is formed. If the oxide stripes are patterned parallel to the long axis of the pit, tunnels result. When the stripes are patterned perpendicular to the long axis, grooves result. If a pinhole cannot be found in the oxide, the etch figures on the bottom of the wafer are rotated 90° from those at the top, and these are used as a guide. If the stripe axes are in each of the $\langle 100 \rangle$ directions in the (100) surface, vertical walls result.

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References

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