Mass Transport of GaN

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Mass transport at the surface will play the most important role in fabricating planar devices, which will be a breakthrough the limitation of performance of the conventional devices of which structure is merely given by stacking. Sub μm size and nm size structure can be easily fabricated by fine lithography technique such as electron beam lithography or focused ion beam lithography. Therefore, fabrication of low dimensional quantum device is also possible by mass transport. However there had been no report on the mass transport properties of group III-nitrides. Here, we show that mass transport of GaN surely occur by thermal annealing in NH_3 containing atmosphere. The surface morphology is found to be influenced due to the strong crystallographic anisotropy of GaN. We also found that dislocations are bent by the faceting process of mass transport, hence dislocation free regions are obtained after mass transport growth [1]. In this report, dynamical process of mass transport is discussed.

GaN 7 μm in thickness was grown by metal organic vapor phase epitaxy (MOVPE) on a sapphire (0001) substrate using a LT-AlN buffer layer. Trench stripes were etched on the surface along the $<11\bar{2}0>$ direction of GaN by reactive ion etching. Several samples of trenches with different depths and widths were prepared. Then, in order to perform mass transport, these wafes were annealed at 1100℃ in a MOVPE reactor. The temperature was monitored using a thermocouple inserted into the graphite susceptor. During annealing, 0.20 mol/min of ammonia with nitrogen gas was supplied. After mass transport these samples are observed by scanning electron microscope (SEM) and atomic force microscopy (AFM).

Figure 1 shows cross-sectional SEM images of before (a) and after mass transport annealed at (b) 900 ℃, (c) 1000 ℃ and (d) 1100 ℃ for 7 min respectively. The width and depth of initial trenches (shown in figure 1(a)) are 3.5 μm and 4 μm respectively. As shown in these images a trench is gradually buried by lateral growth due to mass transport, forming $\{1\bar{1}01\}$ facets which are energetically stable. Strong crystallographic anisotropy modulates the morphology of the trench during mass transport. This is also the same in the case of trench along

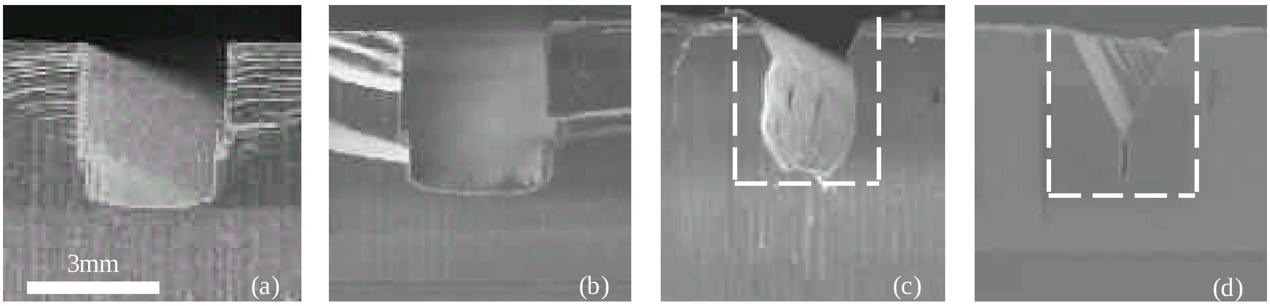

Figure 1 Cross-sectional SEM images of squared trenches (a) before and after mass transport annealed at (b) 900 ℃, (c) 1000 ℃ and (d) 1100 ℃ for 7 min respectively. At higher annealing temperature, trenches are buried with facetting process.

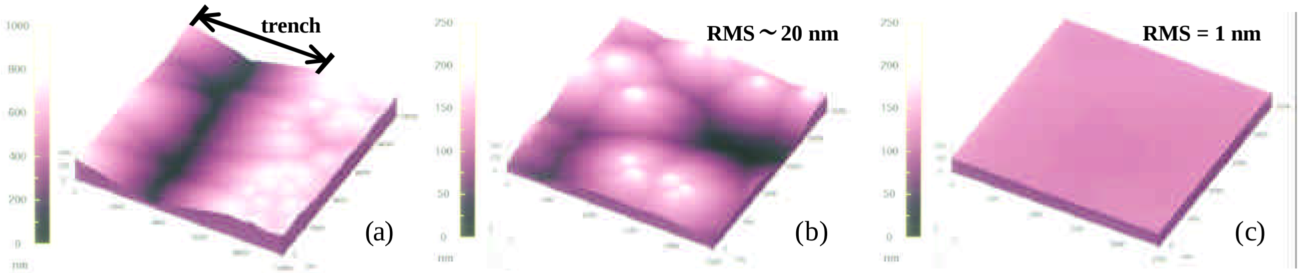

Figure 2 AFM image of (a) near a trench which was buried by mass transport, (b) expanded image of out of trench region, (c) flattened surface after regrowth.

$<1\bar{1}01>$ direction stripe except for another stable facets such as $\{11\bar{2}2\}$ facets forming. The result clearly shows that growth rates becomes higher with increase of annealing temperature. So it is considered that mass transport is obviously a thermally activated process. We estimate the activation energy of mass transport of GaN on the basis of surface-energy-induced model [2], whih is about 4.4 eV. This value includes all components of transport process e.g. decomposition of GaN and NH_3, surface diffusion of free Ga atom and regrowth at trench region. The activation energies of each component are reported by many another researches. Above all the activation energy of decomposition of GaN is dominant (3-4 eV). Thus decomposition at the surface crystal is considered as the rate limiting process in mass transport. In order to understand the mechanism of mass transport in detail, decomposition mechanism on surface of GaN needs to be studied in detail. In figure 1 (d), we can observe that the surface around trench is roughened. An surface AFM image around a trench regeion is shown in figure 2 (a). In this case a trench of which width and depth are 7 μm and 2.5 μm is buried by annealing at 1100°C for 20 min. Figure 2 (b) shows expanded image of out of trench region. Roughness (root mean square : RMS) is about 20 nm. This surface roughening around trench seems to be caused by irregular decomposition due to some kind of crystal defect and/ or the high surface energy. Then to reduce surface energy, crystal morphology itself seems to roughen. The morphology of the surface seems to be also affected by decomposition and diffusion mechanisms. More detailed mechanism will be discussed. To improve the surface morphology regrowth is performed on mass transported wafer. Consequently the surface is completely flattened as shown in figure 2 (c). The RMS after regrowth is less than 1 nm as same as before mass transport. In-plane control properties of composition and electrical conductivity will be also shown.

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