A Mechanism and a Solution to Non-uniformity of pHEMT Wafers Grown by MBE Process

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Abstract

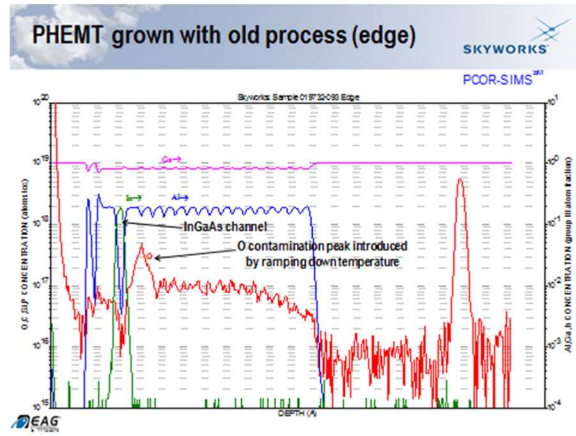
This paper identifies oxygen absorbed in AlGaAs coated growth platens as one of the major sources contributing to non-uniformity of pHEMT epi wafers grown by MBE process. A simple modification of the growth process (recipe) can dramatically reduce the sensitivity of epi uniformity to oxygen content of the growth platens. As a result, highly uniform pHEMT epi wafers can be produced consistently, regardless of growth platen conditions, which greatly improves manufacturing quality and efficiency.

INTRODUCTION

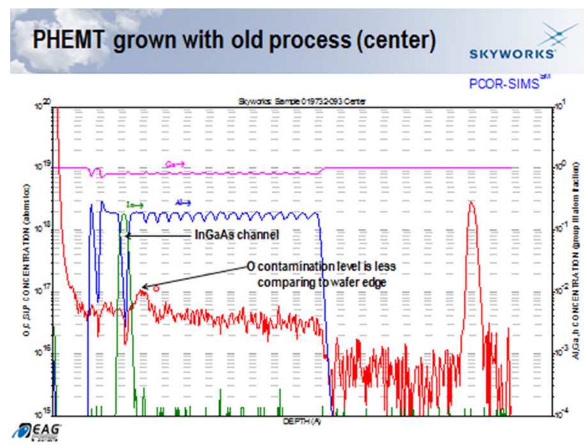
During the pHEMT wafer fabrication process, one of the most important aspects to drive yield improvement is to improve epi cross-wafer uniformity and minimize run-to-run variation. For the MBE pHEMT epi growth process, we have determined that oxygen contamination from growth platens is a major source that can cause poor uniformity of sheet charge and sheet resistance. Oxygen impurities in AlGaAs material introduce deep levels in the energy gap, therefore acting as electron traps. It is well known that aluminum arsenide is very reactive to oxygen to form aluminum oxide and arsenic oxide. The platens used for MBE growth process are coated with the same amount of epi material every time, and the coating accumulates run after run. For GaAs/AlGaAs-based pHEMT growth process, the platens are coated with mixture of GaAs and AlGaAs layers. AlGaAs material accumulated on the growth platens tends to adsorb oxygen when exposed to the atmosphere during the wafer unloading process, and the more the platens are used, the more oxygen will be accumulated on the platens. Oxygen adsorbed on the platens will desorb at high growth temperatures inside the growth chamber, and then re-adsorb on any surface that is cooler than platens. Therefore, the standard MBE process requires frequently cleaning growth platens to minimize oxygen contamination. However, to our knowledge, there is no literature to date that discusses in detail the mechanism of how oxygen contamination affects cross wafer uniformity of the pHEMT epi. In this paper, we discuss how oxygen absorbed in AlGaAs coated growth platens affects uniformity of pHEMT wafers grown by MBE process, and propose a simple solution to grow highly uniform pHEMT epi wafers consistently, and improve manufacturing efficiency.

RESULTS & DISCUSSIONS

A typical double-heterojunction pHEMT structure consists of two AlGaAs barrier layers that sandwich an InGaAs channel layer on top of an AlGaAs and GaAs superlattice (multiple alternating layers of AlGaAs and GaAs). The AlGaAs requires higher growth temperature, while the InGaAs requires lower growth temperature to ensure good crystal quality and sharp, smooth interfaces. Therefore, a temperature ramp from high to low is necessary in a typical pHEMT growth recipe to make a growth transition from AlGaAs to InGaAs. Traditionally, the pHEMT growth process ramps down growth temperature immediately before the InGaAs growth step, to ensure high growth temperature for all AlGaAs layers. Comparing GaAs substrates, typical MBE growth platens made by molybdenum are much heavier in mass, therefore much higher in thermal capacity. When ramping down substrate temperature through a radiation heated manipulator heater, the ramping speed is typically quick enough that the substrates always cool down faster than a platen does due to their smaller thermal capacity. Since residual gas always tends to adsorb on a cold surface, the relative cold substrates will trap the oxygen that is desorbed from the platen during the temperature ramping-down process, until reaching equilibrium, when both the platen and the substrates reach the same temperature. As a result, the epi layer grown during this period will have a high oxygen concentration, which can be detected by a SIMS depth profile of oxygen as an oxygen peak. Fig.1 (a) and (b) show SIMS depth profiles of oxygen across the entire pHEMT layer structure down to the interface between GaAs buffer layer and GaAs substrate (as indicated by a huge oxygen peak). The depth profiles of Al, Ga, and In are also shown as layer markers, and the InGaAs channel layer is indicated by a single indium peak, since there is no other layer using indium. The oxygen peaks near the InGaAs channel layer in both (a) and (b) are marked by arrows. Those oxygen peaks are the evidence that oxygen is transferred from the growth platens to pHEMT epi wafers during ramping down of manipulator temperature as discussed previously. Due to their proximity to the platen, the edges of the wafers tend to adsorb more oxygen than the center, which is evident by comparison of the oxygen concentrations near InGaAs channel between the two locations. In the worst case, the difference can be as much as five times. This is the major source that contributes to cross wafer non-uniformity. Oxygen near devices active layers acts as deep level traps for carriers. Devices fabricated on those areas will have lower current (Idss) and higher turn-on resistance (Ron), which often causes yield loss at the wafer's edge. The problem will progressively get worse after platens get more usage. In the worst case scenario, as high as 10–20% probe yield loss due to low Idss and high Ron can be seen at probe test (Fig. 2).



(a)



(b)

Fig.1. SIMS depth profiles show the location of oxygen contamination peak introduced by old growth platens. (a) Depth profiles probed at the edge of the wafer show higher oxygen contamination peak close to active device layers; (b) Depth profiles probed at the center of the wafer show lower oxygen contamination peak at the same location as shown in (a).

The traditional way to overcome the platen contamination problem is frequently cleaning the platens. However, there are several drawbacks associated with this process. First, it requires several days of reactor downtime in order to clean, degas, and coat a set of platens, which reduces production throughput significantly. Second, during a normal production cycle, as a clean set of platens become "dirty", the contamination will progressively get worse, which introduces inconsistency among the products grown from the "clean" platens to the "dirty" platens. Third, the amount of oxygen accumulated on the platens is not only dependent on the amount of AlGaAs material coated on the platens, but also on the amount of time that the platens are exposed to the atmosphere. Therefore, the amount of oxygen contamination introduced by growth platens not only varies from platen to platen, but also varies from operator to operator who load and unload the platens, which is the main contributor to run-to-run variation of across wafer uniformity. The other possible way to overcome this issue is to reduce temperature ramping down speed to maintain equilibrium temperature between the substrates and the platen all the time. However, slow down of the ramping process requires a growth stop, which increases residual gas adsorption and growth time.

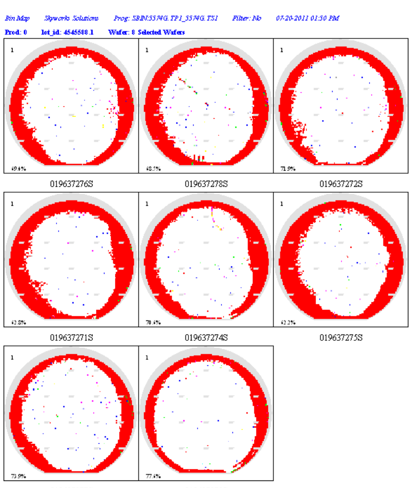


Fig. 2. Probe test data shows 10~20% edge yield loss for low Idss due to oxygen contamination from "dirty" platens

In order to improve across-wafer uniformity and run-to-run consistency, we came up with a simple solution with a different approach, i.e., instead of completely eliminating or minimizing oxygen contamination, we slightly modify the growth process to minimize product sensitivity to oxygen contamination. Noticing that the

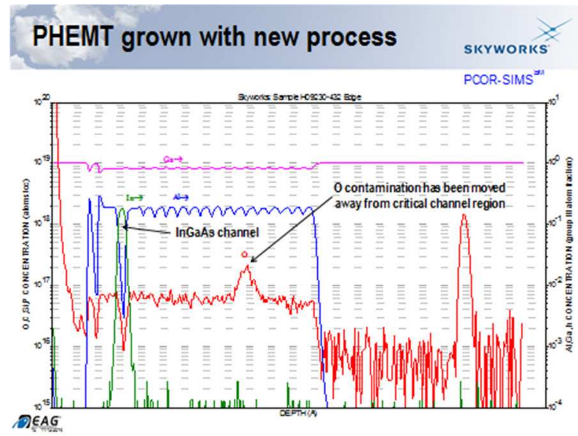


Fig.3. SIMS depth profiles show that the location of oxygen contamination peak from a pHEMT wafer grown by the new process has been moved away from InGaAs channel layer.

location of oxygen contamination accumulated during growth temperature ramping down very close to the InGaAs channel layer, we wondered if we could reduce the impact of oxygen to device characteristics by moving it away from the pHEMT active layers. The way to achieve this was ramping temperature down early during the MBE growth process, so that oxygen adsorption occurred in the region that was "far" away from active device layer (InGaAs channel region). If the distance between the region with high oxygen concentration and the active device layers was great enough, the oxygen would have virtually no impact on device performance. However, there was a limitation to this approach, too. We didn't want to ramp down the growth temperature too early either, so that we would not degrade the AlGaAs material quality. We conducted DOEs to evaluate the tradeoff between cross-uniformity and material quality. After multiple DOEs, we determined an optimum growth process, or recipe. The pHEMT epi wafers produced by this new process not only maintained good material quality in terms of high mobility and strong photoluminescence, but also were highly uniform and consistent from batch to batch regardless of the platens' condition. Since the new process was no longer sensitive to platen condition anymore, it was unnecessary to frequently clean platens. Therefore, with the new process, we were able to not only grow highly uniform and consistent pHEMT epi wafers, but also significantly improve production throughput and reduce manufacturing cost. Fig. 4 shows the probe test yield map of a pHEMT lot using the epi grown by the new growth process. The yield loss (in red) due to oxygen contamination near wafer edges was eliminated. The non-circular yield loss on left and right side of wafer edges is due to a different failure mechanism. Fig. 5 shows a SPC chart of percent standard deviation of sheet resistance of pHEMT epi proces. The data of first half of the chart was collected from the old growth process, and the second half from the new growth process. Each point represents an average value of all wafers grown on the same platen. SPC data clearly indicates that the new growth process dramatically improved both wafer uniformity and process consistency. Not only the mean standard deviation has been reduced to about 1/3 of that of old growth process, but also the run-to-run variation was tightened to about 50% of the original value.

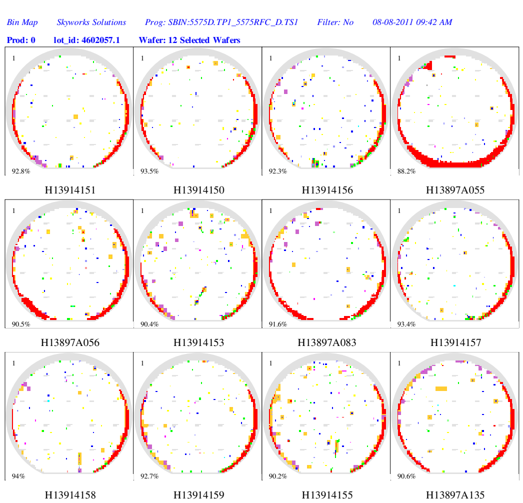


Fig. 4. Probe test data shows minimized edge yield loss from a lot using pHEMT epi wafers grown by the new growth process. The white indicates pass dies, and the red the failed dies.

SUMMARY

Oxygen adsorbed on AlGaAs coated growth platens was determined to be the major source that contributed to non-uniformity of pHEMT epi wafers grown by MBE process. A modified growth recipe that ramps down growth temperature early before the growth of InGaAs channel layer can dramatically reduce the sensitivity of pHEMT product to oxygen contamination. The new growth process can produce highly uniform and good quality pHEMT epi wafers. The DOE and production results prove that the new growth process is a simple but effective way to improve process yield and reduce manufacturing cost.

Fig. 5. SPC chart of run average percent standard deviation of sheet resistance. The growth process is switched over to ramp down manipulator temperature earlier in the growth recipe as indicated.

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ACRONYMS

MBE: Molecular Beam Epitaxy

pHEMT: Pseudomorphic High Electron Mobility Transistor

DOE: Design of Experiment

SPC: Statistical Process Control

PL: Photoluminescence