A mechanism and a solution to non-uniformity of pHEMT wafers grown by MBE process

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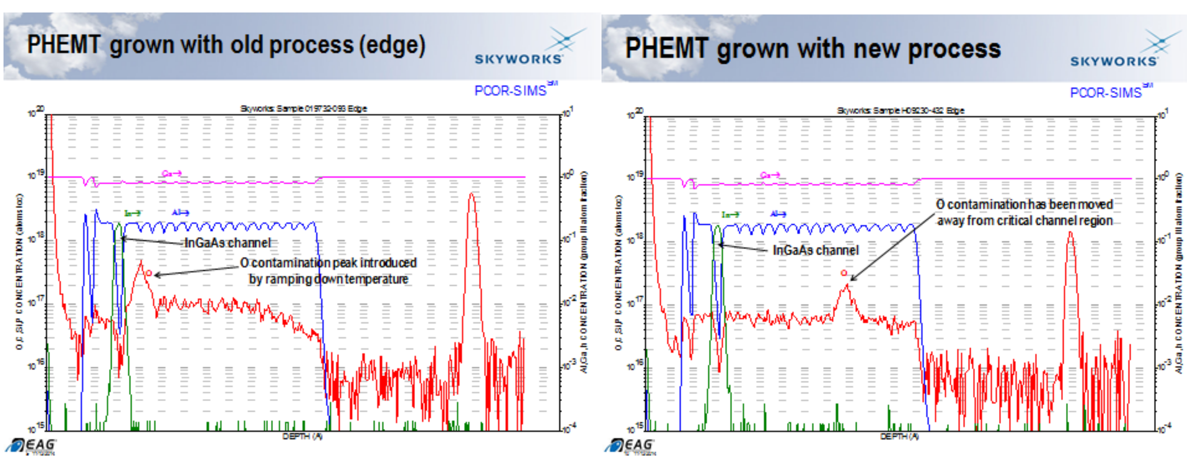
During pHEMT wafer fabrication process, one of the most important aspects to drive yield improvement is to improve epi cross-wafer uniformity and minimize run-to-run variation. For MBE pHEMT epi growth process, we have determined that oxygen contamination from growth platens is a major source that can cause poor uniformity of sheet charge and sheet resistance. Oxygen impurities in AlGaAs material introduce deep level energy in band 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 will be 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 growth chamber, and then re-adsorb on any surface that is cooler than platens. 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 pHEMT growth recipe to make a growth transition from AlGaAs to InGaAs. The traditional 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 platens made by molybdenum have much higher thermal capacity. Therefore, when ramping down substrate temperature through a radiation heated manipulator heater, the substrates always cool down faster than the platen does. Since residual gas always tends to adsorb on the cooler surface, it is unfavorable to have substrate temperature lower than platen temperature, which is the situation when ramping down manipulator temperature prior to InGaAs growth. The substrates cool faster than platen due to their smaller thermal capacity. Therefore, the substrates will trap the oxygen that is desorbed from the platen during the temperature ramping-down process, until both platen and substrates reach the same temperature. As a result, the epi layer grown during this period will have high oxygen concentration, which is evident shown by SIMS depth profiles as an oxygen peak (Fig. 1). Due to their proximity to the platen, the edge of the wafers tends to adsorb more oxygen than the center. Devices fabricated on the area with high concentration of oxygen near InGaAs channel will have lower current (Idss) and higher turn-on resistance (Ron) due to high trap density caused by high concentration of oxygen, which often causes yield loss at the wafer's edge. This 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).

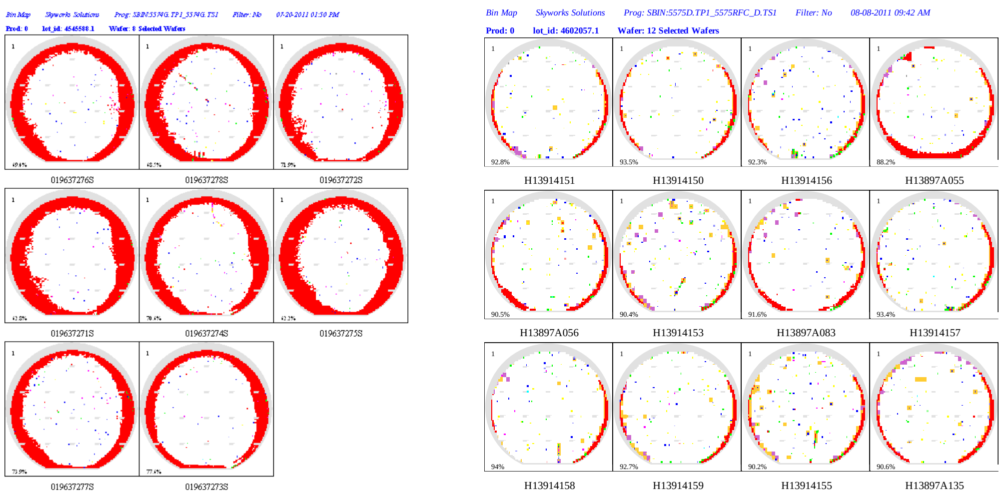
The traditional way to overcome the platen contamination problem is by frequently cleaning the platens. However, there are several drawbacks associated with this process. First, it requires several days of reactor downtime in order to clean, degas, and coat a set of platens, which reduces production throughput. 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 contribution to run-to-run variation of across wafer non-uniformity.

This paper proposes a different solution to resolve this oxygen contamination problem. That is, ramping temperature down early during the MBE growth process so that oxygen adsorption occurs in the region that is "far" away from active device layer (InGaAs channel region). Because the distance between the region with high oxygen concentration and the active device layers is great enough, it has virtually no impact on device performance. The pHEMT epi wafers produced by this new process will be highly uniform and consistent between batch to batch regardless of the platens' condition. Since the process is not sensitive to platen condition, it is unnecessary to frequently clean platens. Therefore, with this new process, we are able to maximize across-wafer uniformity, run-to-run consistency, and production throughput.



(a) (b)

Fig. 1. SIMS depth profiles show the location of oxygen contamination peak introduced by growth platens. (a) Old process: the oxygen contamination peak is very close to active device layers; (b) New process: the oxygen contamination peak is moved away from active device layers.



(a) (b)

Fig. 2. Probe test data shows minimized edge yield loss due to oxygen contamination. (a) Old process; (b) Modified process.

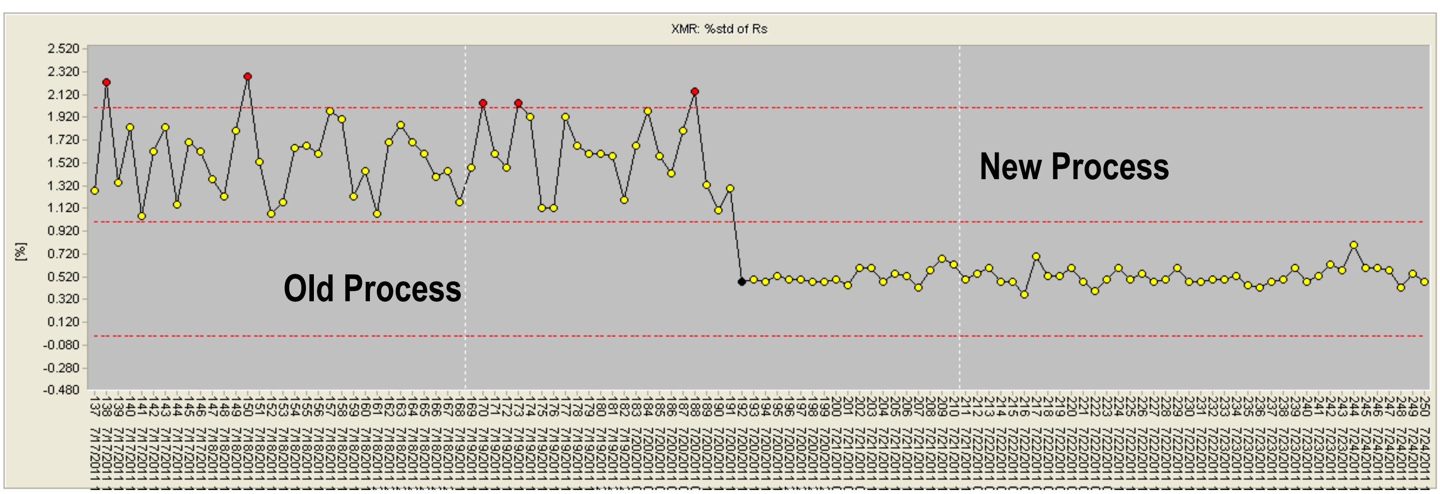


Fig. 3. Standard deviation of sheet resistance SPC chart shows improvement after the implementation of new growth process.