Reduction of Edge Particles on pHEMT Wafers grown by Production Molecular Beam Epitaxy

C. D. Lee*, P. S. Lyman, and W. E. Hoke

Raytheon RF Components, 362 Lowell St., Andover, MA 01810, USA
* Phone: 1-978-684-5437; email: Chae-Deok_Lee@raytheon.com

Keywords: Edge Particle, Oval Defects, Platen, Production Molecular Beam Epitaxy, pHEMT

Abstract

Particles near the wafer edge on pseudomorphic high electron mobility transistor (pHEMT) wafers grown by production molecular beam epitaxy (MBE) were investigated. It was found that the formation of edge particles is associated with decomposition of the GaAs substrate under an As-deficient condition. Therefore, the MBE platen was modified to allow As beam exposure during the growth process, resulting in significant decrease of edge particles.

INTRODUCTION

Particles have attracted much attention from the point of device improvement in III-V compound semiconductor manufacturing technology. Along with rapid technological progress in the wireless communication area, more aggressive control of particle density has been required to improve pHEMT device performance. Aside from common sources of particles such as dust, source spitting, foreign material from chemicals, and residual debris from characterization tools, the particles of interest here are the small particulates formed on both the active film area and exclusion area (non-growth area) of the wafer. Regardless of their detailed physical features, in general, these particles are considered to be small particulates on the surface of the wafers. Under extremely clean ultra high vacuum in the MBE chamber, one can expect these particles are associated with either structural defects or are regular particulates formed during the MBE growth. The former have been found within the film growth area and have been studied extensively over the past 40 years. The latter are around the edge area of the wafer, so-called, edge particles. Although the edge particles directly affect the device performance as well, there have been a few attempts to eliminate them. However, as indicated earlier, the elimination of such particles becomes more important to preserve and improve high production performance of III-V devices.

In this work, we investigate the edge particles in our pHEMT wafers, and present a technique to significantly reduce their density

EXPERIMENTAL

The pHEMT wafers in this study were grown in a multi-wafer production Riber 49 MBE system. The semi-insulating GaAs substrates were loaded horizontally onto a Mo platen, each pocket of which has a lip to hold the substrates for multi-wafer growth (Fig. 4). After loading and buffer chamber degas, the substrates were transferred to growth chamber and heated to 600 ^{o}C to remove the surface oxide. The substrate temperature was monitored by band gap absorption spectrometer and the oxide desorption was observed by RHEED. Following GaAs buffer growth on these clean GaAs substrates, actual device layers were grown. After the growth the particle density and size distribution were measured. To understand the formation mechanism of the particles, SEM and optical microscope images were taken. Furthermore the surface resistivity measurement was done to check the uniformity.

RESULTS AND DISCUSSION

It is well known that the structural surface defects such as pits or hillocks (oval defects) are immobile. In contrast, the edge particles are found to be mobile, and as such are detrimental to device performance. As an example, the SEM picture shown in Fig. 1 displays how the mobile particles are easily crushed into many smaller particles during the wafer delivery.

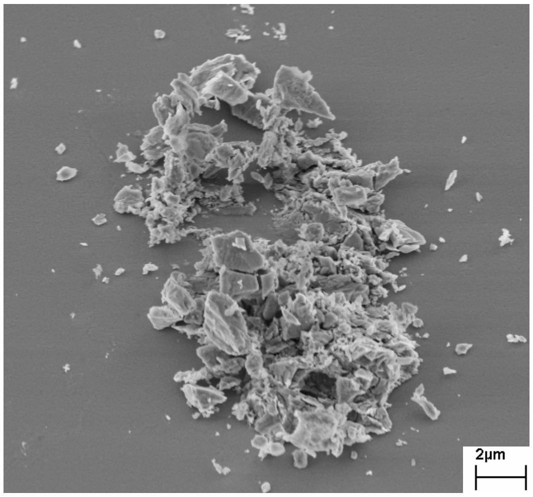

Figure 1. SEM image of crushed edge particle. The debris easily migrates into the device area.

This debris can then migrate into the active film area during wafer processing (sometimes over several centimeters distance toward the active film side).

The distribution of both edge and active film side particles for a scrapped wafer is shown in Fig. 2. The particle density for this scrapped wafer is out of specification, and is much higher than that of our regular wafers. Since the particle detection system is based on the laser scattering technique, it does not distinguish surface defect particles from dust particles within our system resolution. Note in Fig. 2 that the sizes of the particles in the image are exaggerated due to the data image. After many consecutive runs, a high density of edge particles is observed around the wafer exclusion area and blackish materials are seen on the lip of the wafer pockets in the MBE platen. In order to identify the origin of the particles we have used SEM.

First of all, as seen in the bottom insets of Fig. 2, the particles inside the epitaxial growth area on GaAs substrates exhibit a coffee bean shape or irregular core/pit along the <110> direction (a coffee bean shape is an atomic force microscope image). Their lengths are in the range of 0.2-few microns, and along with overall features, they are consistent with those previously reported [1-2]. These are mostly the well-known oval defects with typical density of less than 10 cm^{-2}. Their origin is from Ga spitting, gallium oxide in the crucible, etc. (see Ref. 2 and therein).

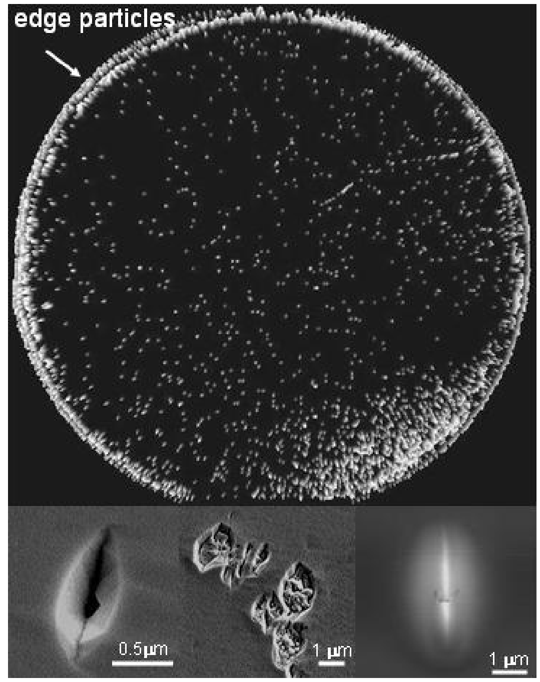

Figure 2. Particles on a 4-inch pHEMT scrapped wafer showing a high density of edge particles. The bottom insets show various oval defects in the active film side.

There have been many reports on the elimination of oval defects, such as effusion cell/crucible modification [3].

On the other hand, particles within the growth edge exclusion area of the MBE platen were observed after several MBE growth runs. The overall shape of the edge particles is very irregular, as shown in Fig 3, compared to oval defects. Again, the most distinctive feature of edge particles is their ability to move on the wafer surface in subsequent processing. In order to find the root cause of edge particle formation, many wafers were investigated by optical microscopy and SEM. Typical edge particles are displayed in Fig. 3. Although they are not taken from one particular wafer over time, we believe that the combination of the pictures could explain the sequential evolution of edge particles over time. It is found that the pits are located in the vicinity of the edge particles (see Fig. 3 (b), (c) and (d)), implying that the particles may originate intrinsically from the substrate. The possible scenario is that at first the pits are formed at high substrate temperature during the oxide desorption (Fig. 3 (a)). Since As is highly volatile, Ga droplets and/or Ga-rich GaAs are left near the pits (Fig. 3 (b)). The pits get bigger over time and the Ga droplets and/or As-poor

GaAs turn to non-stoichiometric GaAs with limited As beam exposure through the gap between the substrate and the exclusion lip of the platen. Eventually, the popcorn-shaped edge particles are fully developed (Fig. 3(d)) and they are located near or where the pits are. This observation indicates that the formation of edge particles is associated with thermal decomposition of GaAs. The observed edge particles are arsenic-deficient (gallium-rich), non-stoichiometric GaAs originating from the decomposition of GaAs substrates, not derived from any mechanically driven scratches. Once the edge particles are formed, the sticking force between the particles and the substrates is either electrostatic or weak liquid (Ga or very Ga rich)-solid interaction, so that they easily migrate during subsequent processing, resulting in significant contamination of the pHEMT wafers.

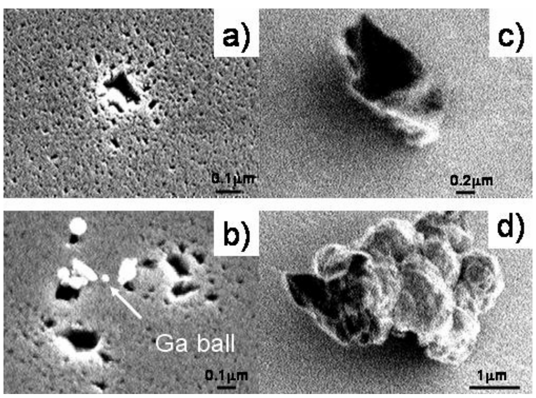

Figure 3. Various edge particles showing the formation of edge particles. Note that the Ga balls are formed near the pits and develop into edge particles.

Based on our experimental observations, MBE platens were modified to suppress the GaAs decomposition. Since the As overpressure suppresses GaAs decomposition at high substrate temperatures, the key feature of the modification is to allow the As molecular beam to reach the edge of the GaAs substrates. Figure 4 shows a schematic diagram of modified platen. As shown in the figure, the edge of the wafer pockets of the platen have been beveled (white arrows in Fig. 4), so that the As molecular beam can reach the wafer edge during the MBE process.

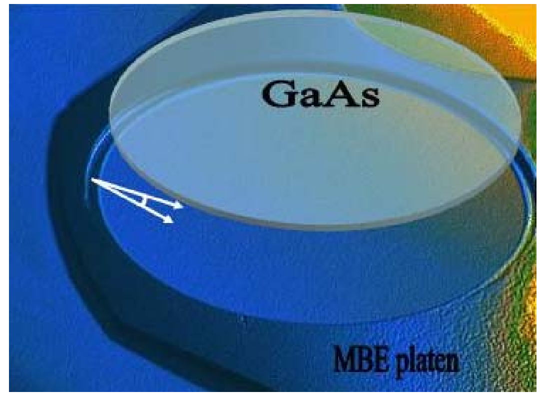

Figure 4. Modified MBE platen which has beveled edge in order to enable As beam access to edge of wafer. The white arrow indicates the beveled angle.

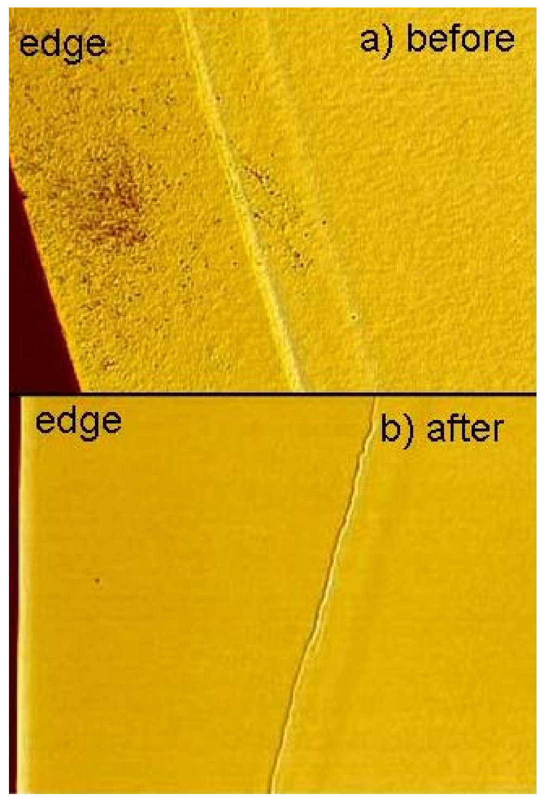

Figure 5. Optical microscope images of the wafer edge after pHEMT growth a) before platen modification and b) after platen modification. The edge particles are seen on the edge exclusion area of the wafer that has a width of 2.5 mm.

After growth with the modified platen, surface resistivity mapping was performed to check the uniformity. Because the contact area between the GaAs substrate edge and the Mo platen is now minimized, there was concern that heating characteristics of the wafers might be unfavorably altered. However, surface resistivity data still show excellent uniformity across the wafer. The typical uniformity is less than 1 %.

As shown in the optical microscope images of Fig.5, with our newly designed platen the edge particles are significantly reduced. Besides GaAs substrates, our platen modification would be useful for material growth on InP substrates, as well. Instead of platen modification, a periodic cleaning for the platen would be helpful to reduce (but not eliminate) the edge particles due to the debris on the platens from previous MBE runs. However it requires additional steps to degas the platen after chemical and/or mechanical cleaning.

SUMMARY

We investigated the origin of edge particle formation. Based on our finding, we modified the platen to allow the As beam to suppress the GaAs decomposition of the substrate. As a result, the edge particle density was reduced significantly.

ACKNOWLEDGEMENTS

The authors would like to acknowledge K.C. Hwang and Rick Beaudoin for SEM observation, Sean Mulligan and Tom McKenna for their efforts in MBE operation, respectively.

REFERENCE

[1] S.K. Mehta, R. Muralidharan, G.D. Sharda and R.K. Jain, Semicond. Sci. Technol. 7, 635(1992).
[2] K. Klima, M. Kaniewska, K. Reginski, and J. Kaniewski, Cryst. Res. Technol. 34, 683(1999).
[3] For example, see VEECO application note No.2/96(1996).

ACRONYMS

MBE: Molecular Beam Epitaxy
SEM: Scanning Electron Microscopy
RHEED: Reflection High Energy Electron Diffraction