Manufacturable AlGaAs/GaAs HBT Implant Isolation Process Using Doubly Charged Helium

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ABSTRACT

Beam of doubly charged helium (He++) with an energy from 380 to 420 KeV has been used to implant isolate AlGaAs/GaAs heterojunction bipolar transistor (HBT) devices. Commercially available 250KV medium current implanters were used with minor equipment modifications. Isolation resistance values decreased from 140 to 20 MΩ as the implant dose was increased from 0.7 to 1.5E14 atoms/cm2. Gain of HBT amplifiers were affected by the implant parameters. Initial reliability study of singly ionized helium (He+) and He++ implanted devices showed no significant differences.

INTRODUCTION

Isolation of AlGaAs/GaAs HBT devices can be accomplished by either etching away the epitaxial layers around the devices and then filling the trenches by dielectric or by partial etching of the surrounding areas followed by ion implantation. Our process employs the partial etching technique. Emitter-up HBTs are fabricated with mesa etching technique that forms a 'base pedestal', which includes emitter and base regions formed by dry or wet etching. The epitaxial layers are grown by metal organic chemical vapor deposition (MOCVD) and the structures have been described elsewhere [1].

Although, the structures are non-planar, the collector and subcollector layers of about 1.5um must be isolated. Good isolation is achieved by inducing just enough lattice damage to convert the silicon doped epitaxial material into semi-insulating material with resistivity ranges of 10 to 100MΩ–cm. The resistance must be stable enough at 400C temperature cycling and be stable under operating conditions. The mechanism of creation of high resistance is believed to be mostly due to damage induced deep levels and in some cases to complex formation with dopants.

The implant depth limits the use of implantation species to light elements. Extensive work has been reported for proton, boron, oxygen [2] and on helium [3]. Proton being the lightest species, appears to be the best candidate for isolation of epitaxial layers. However, reliability problems have been reported for proton isolated devices. Time-dependent current gain behavior of HBT devices has been observed for proton isolated devices. The estimated activation energy of 0.4eV matches that for hydrogen diffusion in GaAs [4]. Thus, the passivation of dopants in the base region by hydrogenation is believed to be caused by the use of proton isolation and subsequent anneal [3].

There is a report of possible radiation hazards associated with implantation of energetic protons and helium [5]. Energetic protons and helium can induce nuclear reactions anywhere the beam strikes, possibly releasing gamma or neutron radiations in the end station area, where they are not normally shielded.

Boron or oxygen can be used for shallower implants. Thus, boron or oxygen are ideal for FET isolations. To use boron or oxygen for HBT isolation, an MeV implanter needs to be used. The equipment and maintenance cost of an MeV implanter is much higher than a medium current implanter.

Although singly ionized helium will produce good isolation properties [3], the implant energy required to isolate to a depth of 1.5um is greater than 400KV, greater than 250KV, the maximum energy of commercially available medium current implanters. In order to avoid the cost and maintenance problems associated with MeV implanters, the use of He++ has been investigated.

EXPERIMENT

Major challenge was achieving a steady He++ beam usable in a production environment. This was achieved by system manufacturers by modifying the source and its parameters. In this study atomic mass unit (AMU) settings of 1,2, and 4 were closely monitored.

Singly charged helium (He+) implant ranges were simulated via Monte Carlo calculations. The software used was a version of the TRIM code capable of simulating the helium bombardment on GaAs. Table 1 shows the implant energies and the corresponding implant profile peak depths. The straggle in the implant direction was found to be ~0.18 um for all simulations. The simulated damage profile peak was within ± 0.05 um of the implant peak position. Experimental verification of the simulation results is under progress.

Table 1. Results of TRIM simulation.

Implant Energy	Peak Implant position
360 KeV	1.17 um
380 KeV	1.21 um
400 KeV	1.27 um
420 KeV	1.32 um

From a family of products, a 1.9GHz, 5 V power amplifier was chosen for this study. More than 30,000 chips have been fabricated, packaged, and tested.

A three-factor design of experiment (DOE) was conducted. Factors were implant dose, energy, and system. He++ ions were implanted at doses of 0.7, 1.0, and 1.5E14 atoms/cm2 and energy setting of 380, 400, and 420KeV. Commercially available medium current implanters were used. Local implanter was used for He+ implantation.

Isolation resistance were measured from 100um wide pads with 3um spacing. Isolation resistance between 20 to 140 MΩ were obtained by varying the three factors. Figure 1 shows the contour plot of isolation resistance, measured in MΩ, as a function of dose and energy. No significant correlation between implanter systems or energy was found. The figure shows isolation resistance to decrease as implant dose is increased. Highest isolation resistance was obtained at a dose of 0.7E14 atoms/cm2.

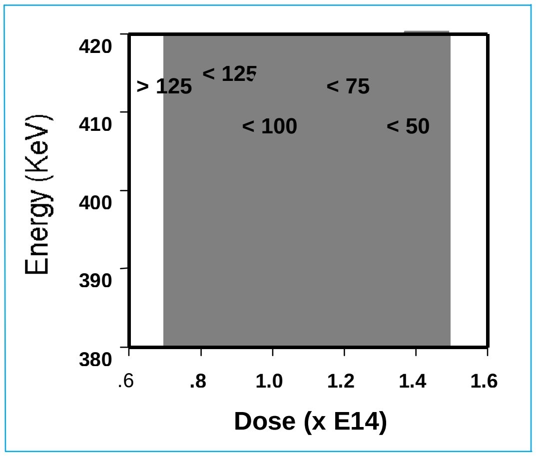

Fig 1. Contour plot of isolation resistance as a function of He++ ion dose and implant energy.

Figure 2 shows the contour plot of the final packaged chip yields as a function of implant dose and energy. Analysis of variance showed that none of the three factors or combination of factors had significant effect on the yield. F-ratio of all terms used in the model were insignificant. However, with an additional data from previous DOE, we were able to gather some insight on the optimal dose. In that DOE, implant energy was held constant at 380 KeV. Doses of 1.0, 1.25, and 1.5E14 atoms/cm2 produced yields of 98%, 91%, and 97%, respectively. In this DOE optimum yield of 94% were obtained at energy settings of 400 KeV, dose of 1.1E14 atoms/cm2, using both systems. Results of these two DOE lots suggest that 1.0 to 1.1E14 atoms/cm2 maybe the optimal dose for this product.

Figure 3 shows the package yield as a function of Large Signal Gain of 5V HBT amplifiers. There were

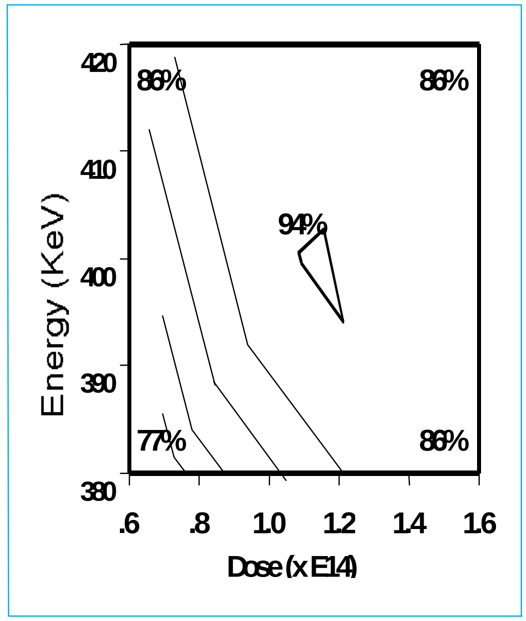

Fig 2. Package yield of 5V, 1.9Ghz HBT amplifier chip as a function of He++ dose and implant energy.

approximately 2200 chips per wafer. Since the upper specification limit of the Gain is 28.5 dB, wafers with higher Gain yielded less. In order to understand the cause of high Gain we have investigated the correlation between isolation resistance and yield. No effect was found.

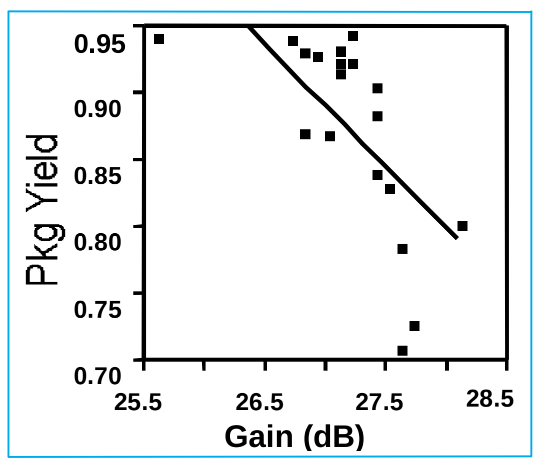

Figure 3. Final package yield of 5V, 1.9Ghz amplifier vs. amplifier gain.

Also, no significant differences in the extracted RF parameters, such as collector base capacitance (Cbc) and unity short circuit current gain (Ft) were found.

Initial reliability study was performed on He+ implanted and He++ implanted devices from the same DOE lot. Ten devices from the process control module (PCM) were used from each of the three wafers. Implant energy of 380 KeV and dose of 1.5E14 were used for all wafers. The test was done at ambient temperature of 165C for 1000 hours. Reliability test showed that reliability of He++ devices were comparable to the He+ implanted devices. The implant specie did not change the failure mode of HBT devices.

SUMMARY

This study has shown AlGaAs/GaAs HBT devices can be implant isolated using doubly charged helium. Commercially available 250KV medium current implanter systems were used with minor modifications. The isolation resistance was found to decrease as the dose increased from of 0.7 to 1.5E14 atoms/cm2. Initial reliabilty test of He+ and He++ implanted devices showed no significant differences in the reliability of devices.

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