A Study of Implant Damage and Isolation Properties in an InGaP HBT Process

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Abstract

Low isolation leakage is important in HBT processes for several reasons: leakage contributes to off state current which degrades battery life in mobile devices, low leakage currents are often used to evaluate device stability in environmental stress tests, and high levels of leakage can interfere with circuit performance by creating parasitic signal cross talk in MMICs.

We will report an experiment conducted to improve the isolation as demonstrated on custom epi structures, using varied implant schemes.

INTRODUCTION

Isolation of InGaP HBTs can be accomplished through formation of separated mesas by etching. This method is undesirable as it creates tall mesas with large topography on the wafers. That topography makes deposition of high quality interconnect layers and planarizing dielectric layers difficult. Alternately, ions can be implanted into the GaAs to render it less conductive. This results in a planar surface, but requires high energy implants of light elements at high doses to isolate thick (> 1 µm), highly-doped layers. More typically, a combination of both approaches is used to reduce the need for high energy implants while limiting the height variations on the wafer.

The isolation implant of InGaP HBTs can be done by implanting a variety of elements to form stable damage profiles. Hydrogen needs to be avoided as it reacts with the carbon base doping and makes unstable devices [1]. The damage introduced during implantation creates traps which reduce the conductivity of doped GaAs layers. It should be noted that too much damage allows for higher conductivity through electron hoping among traps while too little damage creates unstable isolation with excessive leakage. The implant dose and energy can be tailored to create uniform damage profiles of arbitrary depth. Successful modeling allows for optimization in simulation, saving the expense of processing wafers and enabling the use of multiple implants for improved isolation.

To minimize the isolation leakage in our process, we used a combination of simulation and experimentation. Initially experiments were run to verify that adjusting doses and energies could improve the isolation, a model for using damage profiles, as described by Souza [2], was validated for our process, and multiple implants were added and optimized to give low leakage.

SIMULATION

SRIM, an ion implantation simulation tool developed and supported by J. F. Ziegler of IBM and others, was used to simulate the ion profiles and resulting damage. A spreadsheet was then used to adjust doses and sum the effects of multiple implants. Once the damage distributions were modeled for a given energy of implant, the doses could be varied and summed to create a uniform final profile. Figures 1, 2, 3, and 4 show the depth distribution of one type of implant damage, replacement collisions, for varied implant combinations. A Monte Carlo simulation of the implanted ion distribution is compared to a SIMS measurement of a high dose, two energy, B implant in Fig. 2 below on a linear scale. Reasonable agreement can be seen, except the deep channeling tail is not predicted.

Competing requirements for the implant recipes included; achieving the lowest leakage currents at the end of processes, minimizing cost, targeting the capability of existing implant equipment, and achieving lowest energy implants. To process wafers through implant, with additional setup and per wafer costs included, the doubly ionized implants command approximately five times the cost of singly charged implants. Several iterations were run to investigate varied combinations of deep and shallow peaks in the damage profiles. Finally, the combined dose of all implants was varied to optimize the implant for lowest isolation leakage.

Once an optimized implant scheme was developed and verified, an additional experiment was conducted to evaluate several variations on the original implant scheme for levels of leakage and ability to isolate with incompletely etched mesas.

EXPERIMENT

Custom epitaxial (epi) wafers were ordered from a commercial epi supplier. The wafers were specified to simulate our process, which uses a combination of mesa etch (base mesa etch) and ion implantation for isolation. The wafers were grown with varied thicknesses of collector cap on a thick subcollector layer. The goal was to simulate isolation with incomplete mesa etch to establish margin for the process. For our purposes we used 0 kA, 1 kA, 2 kA, and 4 kA of "residual" collector on the subcollector surface. The wafers were then patterned using photolithography to expose only one quadrant at time to the sequence of implants.

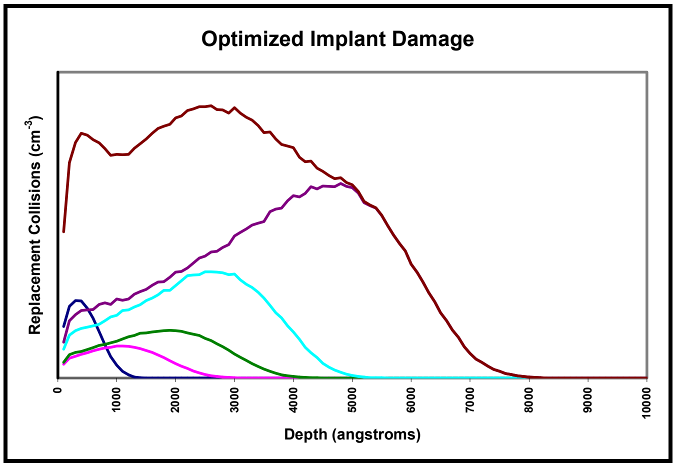

Figure 1: Implant Q1, default five pass implant

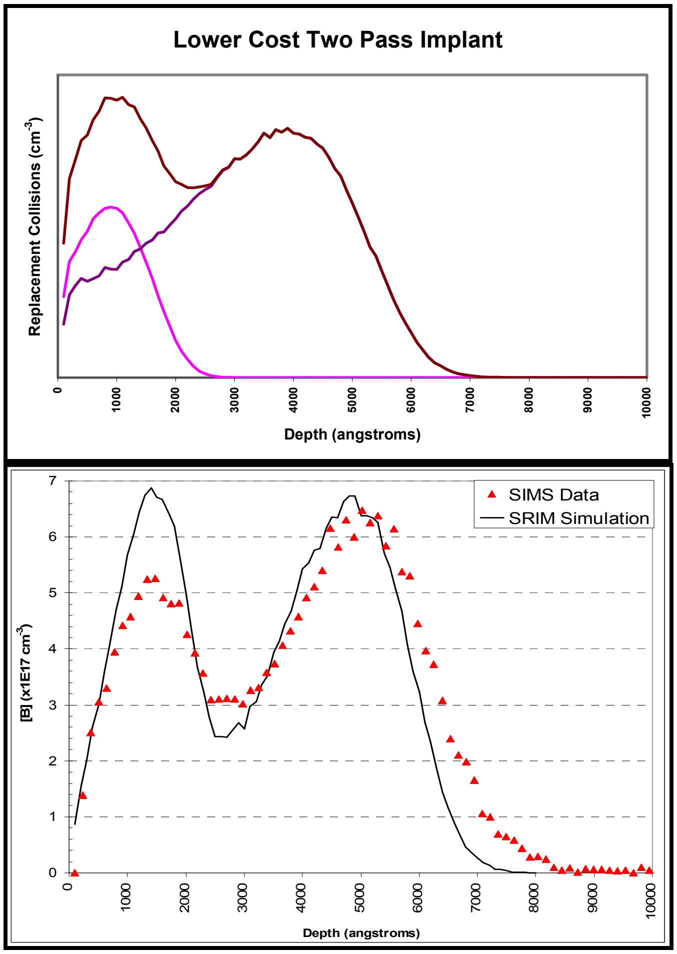

Figure 2: (top) Implant Q2, lowest cost, two pass implant
(bot) Validation of SRIM B depth profile with SIMS

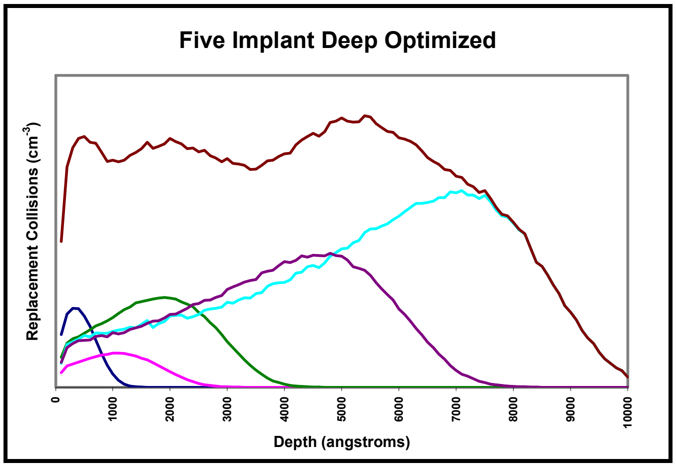

Figure 3: Implant Q3, five pass deep, expensive, implant

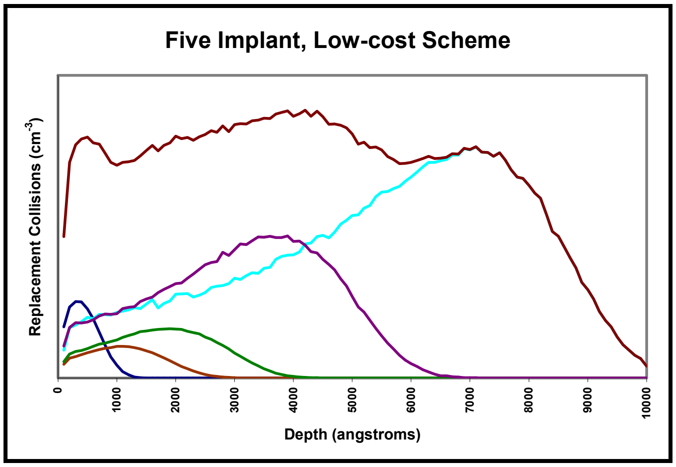

Figure 4: Implant Q4, five pass low-cost implant

Our implants were restricted to ^{11}B, either singly or doubly ionized, with energies ranging between 20 keV and 380 keV. Boron was chosen since it is light enough to give a deep implant at the available implanter energies while being heavy enough to create the desired damage levels in a medium current ion implanter. Pre-existing use of boron in our implanters also made it an attractive choice.

RESULTS

The electrical results were evaluated as leakage current with 10 volts applied to our isolation test structure. The structure is created by forming 7 µm interdigitated fingers of subcollector isolated by 4 µm spaces implanted with the isolation implant. The fingers are shown as dark rectangles in figure 5 and represent large isolated mesas.

Fig. 6 shows measured leakage current vs. quadrant (implant condition, see Table 1) for the various epi substrates. As shown in the leakage current graph, the default implant, Q1, achieved superior results when no excess collector material is

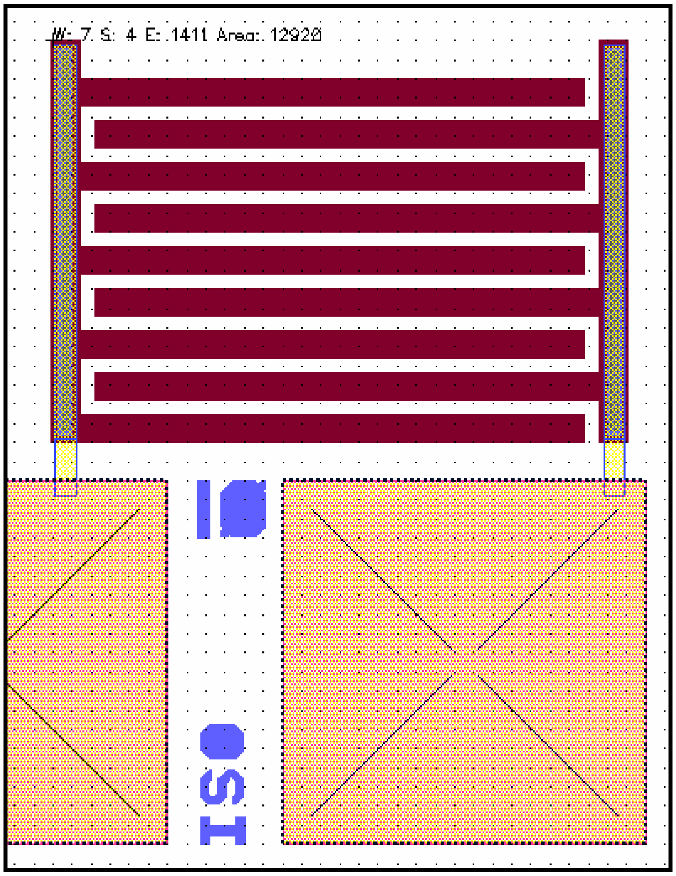

Figure 5: Isolation test structure with 7 µm wide fingers of subcollector separated by 4 µm of implanted field.

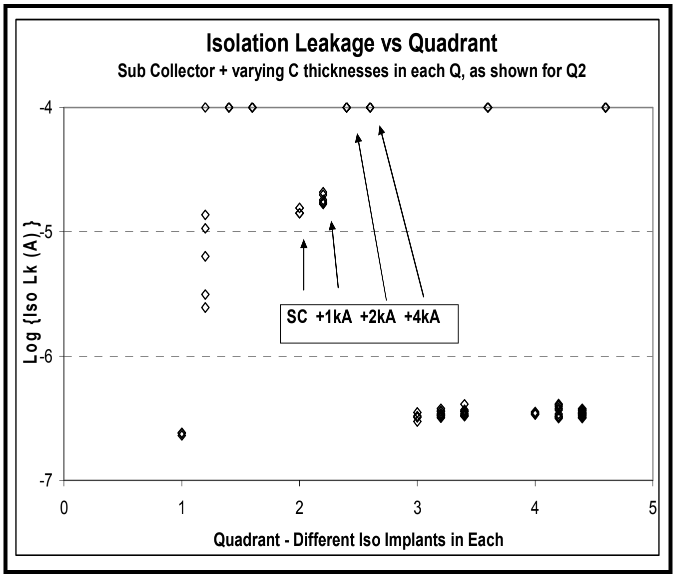

Figure 6: Isolation leakage current vs. implant recipe (QUAD) vs. cap thickness on subcollector

present on the subcollector surface. As material is left on the surface, only the higher energy implants can isolate effectively. With 4000 angstroms of material on the surface even the highest energy implants are unable to give suitable performance.

TABLE 1
MEASURED LEAKAGE CURRENT

Implants Sequence	**Thickness of GaAs on Subcollector (angstroms)**	**Average Leakage (µA)**
Q1	0	0.24
Q2	0	14.6
Q3	0	0.33
Q4	0	0.35
Q1	1000	22.7
Q2	1000	18.3
Q3	1000	0.34
Q4	1000	0.35
Q1	2000	>100
Q2	2000	>100
Q3	2000	0.35
Q4	2000	0.34
Q1	4000	>100
Q2	4000	>100
Q3	4000	>100
Q4	4000	>100

CONCLUSIONS

Use of the replacement collision parameter for predicting isolation implant effectiveness was successful. For our processes, high implant energies gave more process margin, resulting in greater than 2.5×10^9 ohm/sq on wafers that were not isolated by lower energy implants. The low-cost five pass implant, having only one doubly charged implant, was only slightly leakier than the more expensive optimized five pass implant. It was found that both inadequate dose (as produced by the thick cap layer) and excess dose (as produced by the two pass implant) can lead to unacceptably high isolation leakage.

ACKNOWLEDGEMENTS

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REFERENCES

[1] A.G. Baca, C.I.H. Ashby, *Fabrication of GaAs Devices*, The Institute of Electrical Engineers, p.252, 2005

[2] J.P de Souza, et al, *Thermal stability of the electrical isolation In n-type gallium arsenide layers irradiated with H, He, and B ions,* J. Appl. Phys. 81 (2), 15 January 1997