Backside SIMS Analysis and Accelerated Thermal Aging of Optimally Alloyed Ohmic Contacts to MESFETs

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Abstract

Low contact resistances (R_c) of 0.05-0.07Ω-mm were achieved by rapid thermal alloying of AuGe/Ni/Au ohmic contacts to GaAs MESFETs. 'Under-alloyed' contacts with R_c of 0.12-0.16Ω-mm, immediately after alloying, drifted to very high values of 0.4-0.7Ω-mm at the end of fabrication process ('final R_c'), while optimally alloyed contacts had drifted only to 0.1-0.2Ω-mm. Accelerated thermal aging for optimally alloyed samples at temperatures of 185°C to 230°C showed drifts of the order of 10 – 13% in the 'final' R_c values, which is one of the lowest drifts in MESFETs. Backside SIMS studies revealed the differences in the level and extent of diffusion of alloy materials between the 'under-alloy' and optimum alloy samples. Minimal drifts in contact resistances could be attributed to optimum germanium doping of the active layers, and formation of stable compounds in the metal-semiconductor interface and the access regions.

INTRODUCTION

Ohmic contact fabrication to the source and drain regions of MESFETs is a critical process in GaAs MMICs, as source-drain current (I_{DSS}), saturation voltage (V_{sat}) and transconductance (g_m) are significantly affected by this formation. Very low contact resistances (R_c) and good thermal stability of the contacts are indispensable to achieve reliable device performances.

During the course of fabrication of MMICs, we observed large drifts in R_c values of the 'under-alloyed' contacts compared to the optimally alloyed ones [1]. Contacts after completion of fabrication (referred to as 'final R_c') were backside-SIMS profiled to understand the role of diffusion of ohmic contact materials. Samples with optimally alloyed contacts were further subjected to accelerated thermal aging to understand the stability of contact formation.

EXPERIMENTAL DETAILS

Ion-implanted MESFETs with an n^+-GaAs contact layer of thickness of 1500Å, and n-GaAs channel of thickness about 3000-3500Å were fabricated using the typical MMIC fabrication process at GAETEC. AuGe/Ni/Au ohmic contacts with thickness of 1000Å/300Å/3000Å were thermally evaporated and rapid thermal alloyed in forming gas. R_c was measured on TLM structures fabricated along with MESFETs. SIMS profiling of the contacts was performed from the substrate side of the completely fabricated wafers in order to achieve accurate concentration of the diffused contact materials with high depth resolution. Samples were also subjected to accelerated thermal aging tests for 4000hours. In these experiments, contacts alloyed at 400°C for 150 sec had the lowest R_c values (called optimally alloyed), whereas, those alloyed at temperatures lower than 400°C were 'under-alloyed' (390°C), and those above 400°C were 'over-alloyed' (410°C and 420°C), both with high R_c. The 'over-alloyed' contacts exhibited very poor surface morphology and did not yield repeatable electrical results.

RESULTS AND DISCUSSION

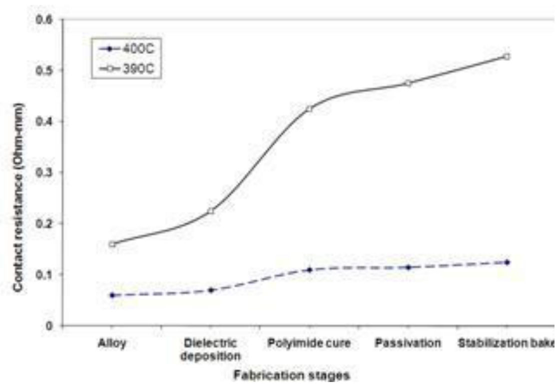

Fig. 1. Drift of R_c during fabrication stages

The fabrication process contains different heat treatments at various stages, significant amongst these cycles being dielectric deposition (250°C), polyimide cure (330°C), passivation (250°C), and stabilization bake (280°C). During fabrication, wafers go through these conditions sequentially after ohmic contact formation, apart from many dehydration bakes and hard-bakes that are part of the lithography processes. Fig.1 shows the large drift of R_c of 'under-alloyed' contacts during fabrication from 0.16 Ω-mm to very high values of 0.4–0.7 Ω-mm at the final level. On the other hand, the distribution of initial R_c of the optimum alloyed contacts was 0.05–0.07 Ω-mm and it increased only to a maximum of about 0.2 Ω-mm at the final level. While, the 'initial R_c' values of the optimally alloyed contacts have approximately doubled at the 'final' level, they are still very low in the usable range of 0.15-0.20Ω-mm. Whereas, for the 'under-alloyed' contacts, it increased more than four times and has very high values unsuitable for device operation.

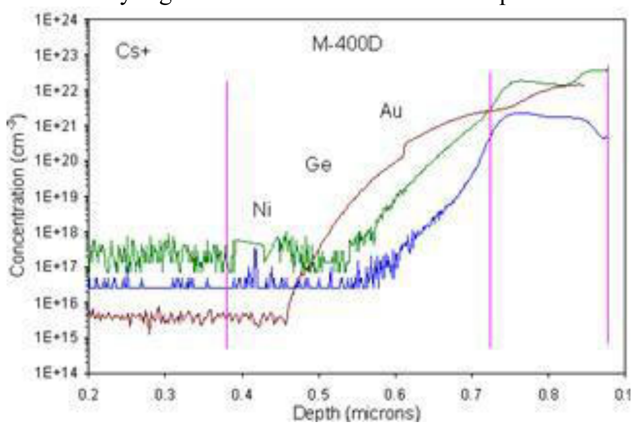

Fig. 2. Backside SIMS profiles of optimally alloyed sample at the end of fabrication processes

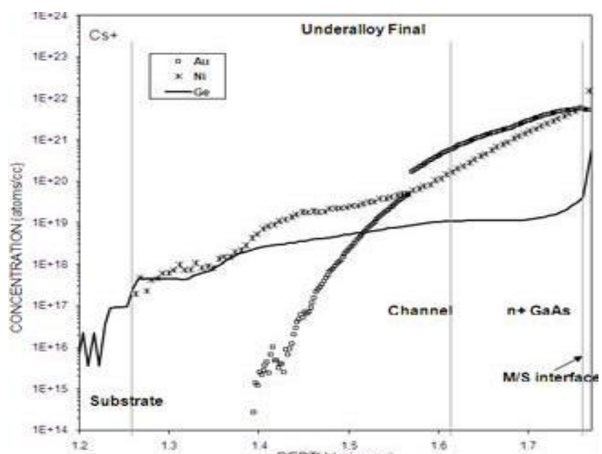

Fig.3. Backside SIMS profiles of 'under-alloyed' sample at the end of fabrication processes

In order to understand the reasons for thermal stability, typical samples at the 'final R_c' stage (from both the alloying conditions) were backside-SIMS profiled. For optimal alloying, very high Ge levels (~10^{21}cm^{-3}) were observed at the M/S interface at 'initial R_c' stage [1]. At 'final R_c', only a small decrease of concentration of Ge was observed, as shown in Fig. 2. Simultaneously, Au and Ni are seen to diffuse slightly into the channel region. However, this additional diffusion is quite small and has not caused any major changes in the 'final' R_c values of the optimally alloyed contacts. In 'under-alloy' sample (Fig. 3), it can be seen that there is an anomalous diffusion of Ni and Ge deep into the channel, and even into the semi-insulating substrate far more compared to Au, while Au has diffused upto the middle of the channel. The concentration of Ni is quite high in the n^+ and channel regions, i.e., 10^{20}cm^{-3} and 10^{19}cm^{-3}, respectively, compared to Ge, which is in the range of 10^{19}cm^{-3} and 10^{18}cm^{-3}, respectively. The incoherent diffusion of Ni and Ge deeper into the substrate, compared to Au, is probably due to under alloying and the cumulative heat treatments during device processing. This can lead to non-formation of compounds such NiAs, NiGeAs which are known to significantly reduce R_c [2]. We feel that this could be due to non-availability of Ga vacancies. Additionally, the M/S interface shows a large reduction in Ge levels to 10^{19}cm^{-3}. Any such decrease of surface concentration of Ge would increase the sheet resistivity of the 'reacted' GaAs region near the surface. Therefore, the contact resistance had deteriorated to a very high value at 'final R_c' stage.

The thermal stability of the optimally alloyed contacts was further confirmed by accelerated aging tests, which were conducted at three different temperatures, viz., 185°C, 200°C and 230°C, on different sets (of 12 structures each) of assembled TLM structures for 4000 hours each. An occurrence of a drift of at least +20% in the value of R_c is usually chosen as a failure criterion for evaluation of life. During our experiments, a +20% drift in the 'final R_c' value was initially proposed, but it was noticed that even after 4000 hours, there were no occurrences of any drift of +20%, but only +10%, or at the most, +13% had occurred during the course of experiments. Hence, for the purpose of calculations, drift values near +13% were treated as failures of +15% for obtaining the worst-case life estimation analysis. Drifts of 10% were also compared in order to ascertain if the contact degradation mechanism was due to a single mechanism [3]. Therefore, the failure time t_F was defined as that time at which 'final R_c' increased by factors of +10% or +15% from the value prior to tests.

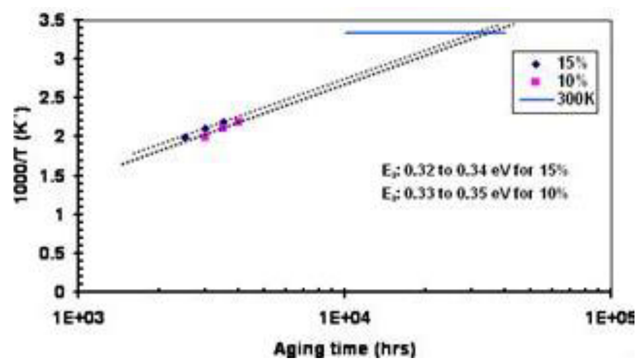

Fig.4. Arrhenius activation energy plots of inverse of absolute temperature vs. failure time

Fig. 4 is a graph of natural logarithm of the failure time against the inverse of absolute temperature. The experimental plots of +15% as well as +10% drifts have resulted in straight lines. Extrapolation to 300K reveals the operating life of the contact. As per this graph, the estimated life would be about 30,000 hours, or longer, for drifts of +10% to +15%. The activation energies range between 0.32

to 0.35eV. This estimation has considered only very low values of drift since drifts more than +13% did not occur in any of the TLM structures. In principle, even a drift of +20% also does not cause any appreciable change in the RF characteristics of MESFET [4]. Therefore, consideration of +10 to +15% drifts was highly severe and, practically, life of the contacts would be much longer if we consider drifts of +20%. This showed that the contacts were extremely reliable and thermally stable. This is possibly one of the lowest drifts reported in literature, to the best of our knowledge. The above results indicate that the contacts have shown minimum degradation even after subjecting the TLM structures to 4000 hours of aging tests. In the optimally alloyed sample, the contact resistance did not increase drastically at the 'final R_c' stage as well as after aging. This is probably due to very high Ge concentrations in the n^+ layer. It can be also noticed that Ge concentration at and near the n^+-n interface still is retained at a very high level. Further, formation and dominant occupation of the thermally stable Ge-rich compounds during optimum alloying possibly bestow thermal stability [5]. This explains the low drift percentages during aging studies.

CONCLUSIONS

Backside SIMS analysis revealed the extent of diffusion of the contact materials into the active layers during fabrication stages. The optimally alloyed sample showed minimal diffusion while the 'under-alloyed' sample showed incoherent diffusion leading to high R_c values. This has resulted in thermally stable and reliable contacts.

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REFERENCES

[1] G. Sai Saravanan, K. Mahadeva Bhat, Sandeep Chaturvedi, H.P. Vyas, S.D. Prasad, R. Muralidharan, K. Muraleedharan and A.P. Pathak, 'Reliability studies of AuGe/Ni/Au ohmic contacts to MESFETs by accelerated thermal aging tests', in 14th IEEE Int. Workshop on Physics of Semiconductor Devices, Mumbai (2007).

[2] T. S. Kuan, P. E. Batson, T. N. Jackson, H. Rupprecht and E. L. Wilkie, 'Electron microscope studies of an alloyed Au/Ni/Au-Ge ohmic contact to GaAs', J. Appl. Phys. 54(1) (1983)

[3] K. Prasad, L. Faraone and A. G. Nassibian, "Thermal stability of ohmic contacts to n-GaAs formed by scanned electron beam processing," *J. Vac. Sci. Tecnol. B*, vol. 8, no. 4, pp. 618-624, Jul/Aug. 1990.

[4] C.E. Lindsay, R. F. B. Conlon, P. H. Bolbot, F. Garat and L. Marchand, "An assessment of long term degradation mechanisms in GaAs MMICs," *Proc. third ESA Electronic Components Conference, ESTEC*, pp. 41- 44, July 1997.

[5] M. Ogawa, "Alloying behaviour of Ni/Au-Ge films on GaAs," *J. Appl. Phys.*, vol. 51, no. 1, pp. 406–412, Jan.1980

ACRONYMS

MESFET: MEtal Semiconductor Field Effect Transistor
MMIC: Monolithic Microwave Integrated Circuits
TLM: Transfer Length Method
SIMS: Secondary Ion Mass Spectrometry
M/S interface: Metal-Semiconductor interface