New insights into formation of Ni-based alloyed Ohmic contacts to GaAs

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Abstract

Magnetism of the alloyed AuGe/Ni/Au Ohmic contact metallization to GaAs, arising from the use of ferromagnetic Ni, is investigated in the context of high sensitivity Hall magnetic field sensors with integrated FET circuits using GaAs/AlGaAs 2DEG structures. Magnetization measurements provided some interesting insights that the Ni undergoes solid-state solubility-limited dissolution into the AuGe layer during the anneal prior to alloying. This results in increase of the melting temperature of the AuGe layer. The process renders the structures non-magnetic on cooling, implying that the conventional process is suitable for room temperature applications of the sensors with the circuits.

INTRODUCTION

GaAs/AlGaAs multilayer structures, incorporating the 2-dimensional electron gas (2DEG) layer, which have well known applications in infrared sources/detectors and in high-speed electronic devices e.g. (HEMT), also have another, a not-so-familiar application in fabrication of high sensitivity Hall-effect based magnetic field sensors [1]. These sensors, easily microfabricated, are useful for mapping magnetic fields close to surfaces, eg, in non-destructive testing and magnetic microscopy. Researchers in this area have used non-magnetic variants like Cr, Ti etc for Ni as the interlayer in the well-tested recipe (AuGe/Ni/Au) for Ohmic contact formation [2]. This variation was motivated by the possible distortion of the measured field by the ferromagnetic Ni. However this involves a trade-off in contact resistance and surface morphology. This trade-off is particularly disadvantageous if HEMT circuits are to be integrated with the sensor.

Explicit studies of the magnetic properties of the processed Ni-containing Ohmic contact metallization structure, together with contact resistance and surface roughness measurements, are rare in literature. Our studies in this direction have given some new insights into the changes that take place during processing in such an Ohmic contact metallization structure, prior to the alloyed-contact formation which are discussed in this paper.

EXPERIMENTAL DETAILS

The GaAs/AlGaAs multilayer structure, grown by Molecular Beam Epitaxy (MBE), has a n+ cap layer on which metallizations with different AuGe compositions (eutectic (88:12 wt %) and off-eutectics (95:5 and 97.3:2.7 wt %)) were deposited in the sequence substrate/AuGe/Ni/Au. AuGe and Au layers were deposited by thermal evaporation and Ni layer by electron beam evaporation. The contact resistance was measured using the Transfer Length Model (TLM) by lithographically patterning a transmission line pattern.

Magnetic measurements were carried out using a Vibrating Sample Magnetometer on samples that were rapid thermal annealed and cooled down to room temperature. Grazing incidence XRD and SEM was used to study the changes in the metallization structure on annealing.

RESULTS AND CONCLUSION

The as-deposited film structures are ferromagnetic (Figure 1). The magnetization progressively decreases to zero as the anneal temperature is increased. Decrease of magnetization is observed even at anneal temperature as low as 100^{o}C.

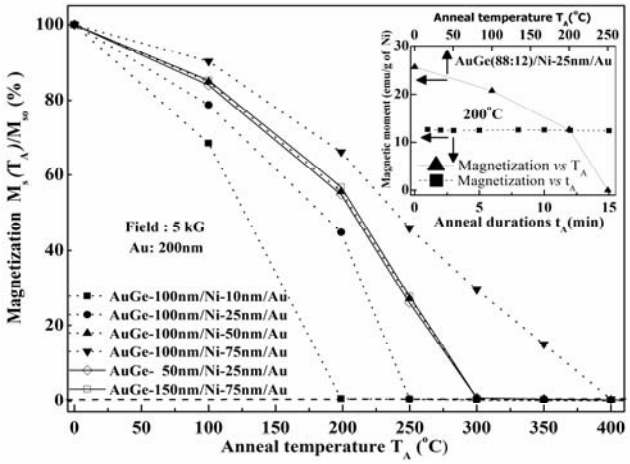

Figure 1: Anneal temperature (T_A) dependence of the fractional saturation magnetization. M_{s0} is the saturation magnetization of the un-annealed sample. The inset shows the time dependence of saturation magnetization.

The magnetic measurements, apart from confirming that the contacts prepared by the conventional recipe, involving anneals at ~400C are non-magnetic (Table 1), provided

some additional insights into changes taking place in the metallization structure prior to alloying.The data in figure 1 show that the amount of Ni converted to non-magnetic phase is proportional to the AuGe layer thickness.

Magnetization measurements as function of anneal durations (prior to alloying), show that the transformed Ni fraction is independent of time (inset of Figure 1) and depends only on anneal temperature. Thus Ni dissolution into AuGe appears to be solubility limited rather than diffusion limited at these time and temperature scales. The solubility of Ni in AuGe increases with anneal temperature and decreases with decreasing Ge content in the AuGe alloy (Figure 2).

Cross sectional SEM micrograph of a sample which has been annealed just sufficiently for its magnetization to vanish, (but alloying has not yet taken place) still displays distinct layers, indicating a transformation of the metallization structure to the non-magnetic state occurs in the solid state. Grazing incidence XRD data on a sample (AuGe (88:12)/Ni-25nm/Au) annealed at 300^{o}C, and cooled down to room temperature reveal the formation of NiGe phase. A picture consistent with these results is that *Ni layer goes into dissolution into the AuGe layer in a solid-state, solubility-limited process well before alloying of the metallization structure with GaAs takes place* and precipitates as non-magnetic NiGe compounds on cooling.

The contact resistance and surface roughness, as a function of, Ni layer thickness with three AuGe compositions is summarized in Table 1. The minimum in the contact resistance is obtained for Ni layer thickness of 25-30 nm. Increasing the Ni layer thickness or decreasing the Ge content from the eutectic AuGe alloy decreases the surface roughness but increases the contact resistance. The use of off-eutectic composition of the AuGe alloy (95:5) is a better compromise for trading off contact resistance for smoother surface than increasing Ni layer thickness (table 1).

TABLE I: Contact resistance, surface roughness and the magnetic-to-non magnetic transition temperature, with different Ni layer thicknesses and alloy compositions.

AuGe alloy composition	AuGe layer thickness (nm)	Ni Layer Thickness (nm)	Contact resistance (Ω-mm)	Surface roughness (nm)	Magnetic to non-magnetic transition temperature (^{o}C)
88:12	100	Ni = 25	0.05±0.01	21 ± 3	200 - 250
88:12	100	Ni = 30	0.07±0.005	21 ± 2	200 - 250
88:12	100	Ni = 50	0.90	11± 1	250 - 300
88:12	100	Ni = 75	1.40	7.5 ± 0.5	350 - 400
88:12	50	Ni = 25	2.95	10.5 ±1	250 - 300
88:12	150	Ni = 75	0.95	11 ±1	250 - 300
95:05	100	Ni = 30	0.17 ±0.02	5.5 ±0.5	250 - 300
97.3: 2.7	100	Ni = 30	1.30	4.5 ±0.5	400 - 430

The films' scratch resistance improves as Ni dissolves into the AuGe layer, as determined by results of nano-indentor scratch tests. Temperature dependence of contact resistance performed down to 4K displays both tunneling and thermionic emission characteristics and the effective barrier height in contact structures with enhanced Ni layer thickness or decreased Ge content in the AuGe alloy increases in relation to the optimal structure (eutectic AuGe with 30nm Ni).

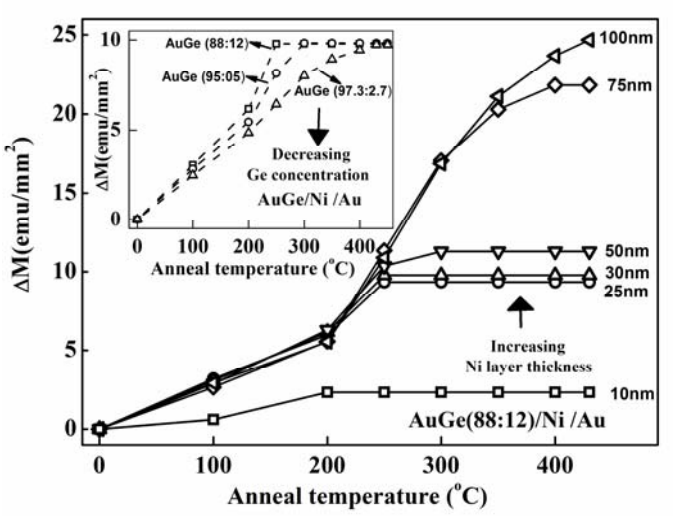

Figure 2: Effective thickness of Ni layer transformed to non-magnetic phase on annealing at various temperatures. (ΔM is the decrease in magnetization per unit area).

Further, Differential Scanning Calorimetry scans indicate an increase in the melting temperature of the metallization structure with increased Ni dissolution, arising from an increase of initial Ni layer thickness. As expected, the melting temperature of the metallization structure also increases with decreasing Ge content from that of the eutectic AuGe alloy.

CONCLUSIONS

Magnetic studies of the popular AuGe/Ni/Au type of contacts reveal that Ni dissolves into AuGe layer prior to alloying with GaAs in a solid state solubility limited process. This dissolution increases the melting temperature of the metallization. The Ni dissolution and use of off-eutectic AuGe improves morphological quality of processed contact, but requires trade off in contact resistance.

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