Processing and Properties of PdGe Ohmic contacts to GaAs

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ABSTRACT

The palladium-germanium PdGe metal system has received considerable attention in recent years as a potential replacement for the almost universally employed Au-Ge-Ni ohmic contact metallurgy on GaAs devices. The perceived advantages of this system are in part derived from the absence of eutectic phase formation during alloying; thereby producing a 'non-spiking' ohmic contact with a high degree of morphological stability. However, these reports typically deal with simple test structures (usually TLM patterns) and rarely test the ohmic contact in the more familiar environment whereupon it is further processed and contacted by a local interconnect metal. Literature reports of such structures, whilst much scarcer, do tend to suggest that there may well be a propensity of the PdGe contact to be degraded by the action of some commonly employed processing chemistries. This paper will discuss possible solutions to the potential problem areas for ohmic contact degradation; most notably prolonged exposure to aqueous media. Experimental test data will also be supplemented by a microstructural characterization to illustrate both the formation and degradation processes in this ohmic contact metallurgy. Finally a proposed methodology for the attainment of a low and stable contact resistance utilizing PdGe ohmic contacts will be presented

INTRODUCTION

The particular nature of the ambient exposed GaAs surface results in the creation of a level of interface states, or traps, sufficient to cause Fermi level pinning of the semiconductor surface. This phenomena is ultimately manifested as a propensity for GaAs to form rectifying or Schottky barriers with a contacting metal rather than a low resistance junction, as would be required for an ohmic contact. [1] Currently employed contacting methodologies based on the metallurgy of AuGeNi are believed to overcome this interfacial barrier by a complex alloying process whereby Ge protrusions into the GaAs create localized field emission sources of charge injection. [2] However, the AuGe low temperature eutectic that is responsible for the beneficial interfacial mixing effects also produces a final characteristically mottled looking metal contact with a distinct lack of morphological stability. Notwithstanding a desire to produce ohmic contacts with increasingly lower contact resistance, the constant drive to reduce device dimensions has led to an increased effort to create an ohmic contact with superior lateral stability. Recent literature reports have proposed a substantially different class of ohmic contacts based on the solid state transport and regrowth of epitaxial germanium at the GaAs/metal interface. [3] A low resistance contact is thus thought to ensue through a combination of Schottky barrier lowering by the removal of surface states by the epi-Ge and a near surface doping of GaAs by Ge to create a highly N+ doped region. PdGe based contacts are representative of this class of solid state ohmic contact. With Pd deposited as the base layer on GaAs, the Ge initially reacts with the Pd to form a series of intermetallics before transporting 'excess' Ge to the GaAs surface which subsequently regrows in an epitaxial layer. The solid state mechanism thus avoids any liquid forming eutectics and imparts a high degree of dimensional stability to the alloyed contact. The cross-sectional appearance of such an alloyed contact is shown below as figure 1.

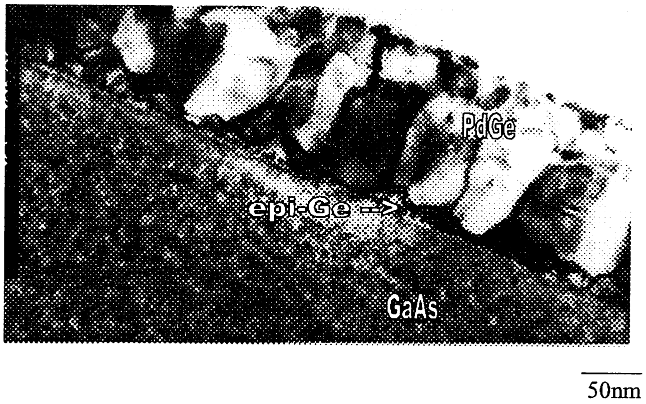

Fig. 1 TEM bright field image of a PdGe alloyed contact on GaAs. Resulting phases of PdGe, epi-Ge and GaAs substrate are clearly evident.

A quick perusal of the literature accounts of PdGe based ohmic contacts seems to indicate a myriad of alloy compositions and alloying temperatures that can seemingly produce contact resistances in the 10^{-7}–$10^{-6}\Omega cm^2$ range. [4] However, the vast majority of these studies are laboratory based investigations that tend not to reflect the more 'real world' device scenario where ohmic contacts are subsequently further processed and themselves contacted by a local interconnect metal. Though sparser, studies that include such processing tend to suggest that there can be considerable issues with the chemical stability of PdGe based contacts - particularly when exposed to plasma etchants, de- ionized water and other organic solvents. [5] The following report addresses the processing of PdGe ohmic material in a typical high volume GaAs manufacturing environment. Initially we will address the issues surrounding the alloy composition and heat treating before highlighting areas where the lack of chemical stability may be a real concern. This is for the most part presented in relation to the more standard AuGeNi contact in order to ascertain both the perceived advantages and drawbacks inherent to this technology. Finally, in the light of other proposed methodologies for imparting a chemical stability to PdGe based contacts, we will present our own variations of PdGe protection that may ultimately allow introduction of these solid state contacts.

COMPOSITIONAL EFFECTS ON ALLOYING.

Compositional considerations in the formation of an epitaxial germanium interfacial layer dictate that the deposited metal stack contain germanium in excess of that required to form the stoichiometric PdGe. The stoichiometric PdGe formation may thus be expressed in terms of layer thicknesses as:

$$1.00\text{Å Pd} + 1.54\text{Å Ge} \rightarrow 2.13\text{Å PdGe}.$$

For a total thickness of 700Å of palladium used in our in deposited PdGePd ohmic metal stack, a 1078Å layer of germanium would be required for PdGe stoichiometry. We thus evaluated any effect of excess Ge content by performing alloy studies on the following compositions.

TABLE 1.
Composition of alloys with variable amount of excess Ge.

Alloy #	Pd layer*	Ge layer	Excess Ge
1	700Å	1200Å	122Å
2	700Å	1500Å	422Å
3	700Å	1800Å	722Å

* Note that Pd is split as 500Å base and 200Å cap in PdGePd sandwich.

The corresponding contact resitances displayed for these alloys at different alloy temperatures was then determined by the transmission line method (TLM) and shown as figure 2.

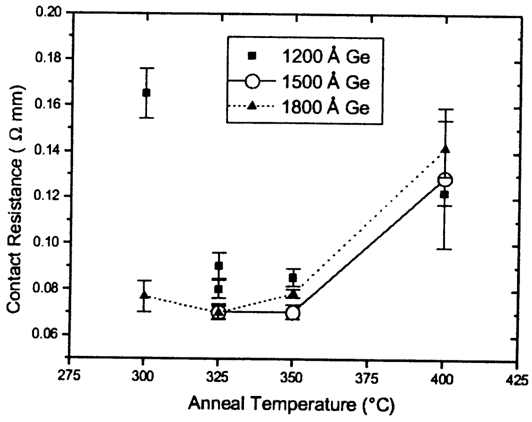

Fig. 2 Contact resistances as a function of annealing temperature as a function of Ge thickness.

The displayed curves, whilst indicating no great disparity between compositions, would seem to indicate an optimum composition of 700Å Pd and 1500Å Ge and an alloy temperature of ca. 325C. The U-shaped alloy curves show that for isochronal annealing, a greater excess of germanium allows attainment of optimal contact resistance at a lower temperature. Conversely, the effects of over-alloying are also observed at lower temperatures than alloys containing lesser amounts of excess germanium. Though not treated here, this observation may shed light on the overall mechanisms of ohmic contact formation in this system.

Of further note here is the morphological appearance of the final alloyed contact. This is shown compared to a typical AuGeNi ohmic as figure 3. Comparison of these figures adequately demonstrates the dimensional stability inherent to the PdGe system. Alloyed metal surfaces remain' mirror-like.'

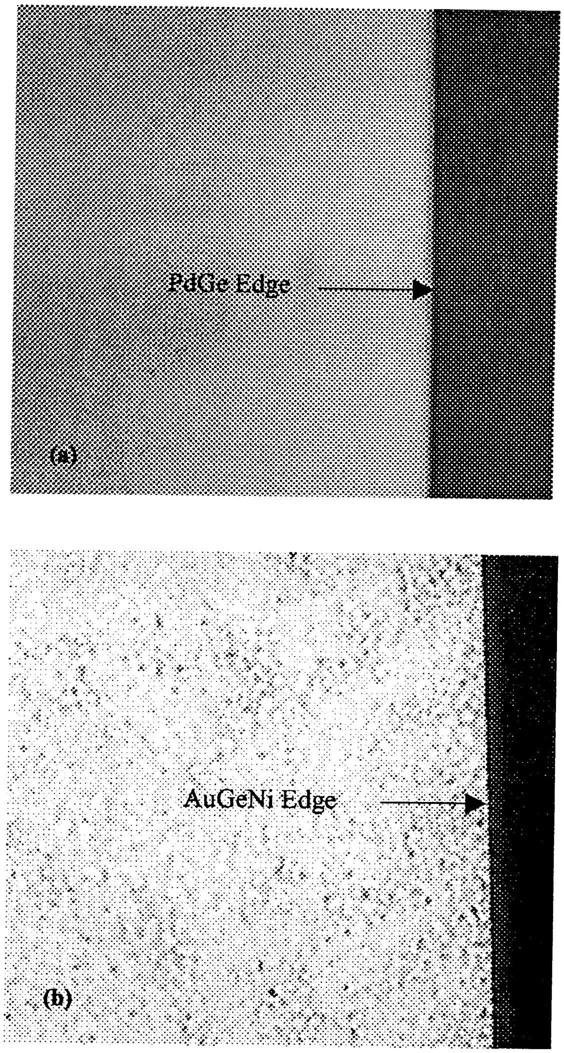

Figure 3. Optical micrographs of post-alloyed (a) PdGe and (b) AuGeNi

PdGePd contacts with the composition 700Å Pd and 1500Å Ge were alloyed at 325C and then processed through industry standard photolithographic and etch processes to form an interconnected structure representative of a locally connected source or drain region of a field-effect transistor (FET).

The processing sequence employed in this regard is schematically shown as figure 4.

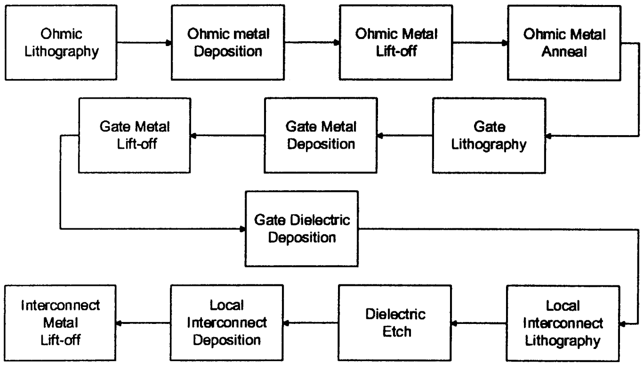

Fig. 4 Fabrication sequence employed to assess PdGe ohmic contact degradation.

It must be noted that PdGe contacts can routinely be processed completely through a total fabrication sequence without any degradation – yielding stable contact with resistivities in the 0.06Ωmm range. However, sporadic experimental wafer lots can also be observed to exhibit severe contact degradation yielding ohmic contact resistances orders of magnitude higher. It was these 'flyers' that prompted investigations into the stability of PdGe alloyed contacts in our process chemicals and to ascertain the process latitude inherent to this metal system. The process chemistries employed through the fabrication sequence depicted above can be generically divided and any degradation effect assessed through isolated exposure of a TLM structure. The results of this analysis are presented as Table 2. Note comparative data for AuGeNi has been included where appropriate.

TABLE 2.
PdGe and AuGeNi contact degradation in common processing media.

Chemical Exposure	PdGe contact degradation	AuGeNi contact degradation
Organic Solvents	No effect	No effect
De-ionized water 1	Mild	No effect
De-ionized water 2	Variable. Mild to very severe	Very mild
Buffered oxide etch	Severe	No effect
Fluorine Plasma etch	No effect	No effect

Organic solvents refer to photoresist primers, photoresists, alcohols and acetone.

Deionized water 1 refers to a single exposure to overflow/dump rinsing followed by spin rinse drying as would be typically employed in surface preparation procedures

Deionized water 2 refers to an extended immersion in d.i. water. This is designed to simulate both gross misprocessing and reworking of wafers through surface preparation steps and ultimately represents a process latitude for such steps.

The buffered oxide etch (BOE,) employed in a greatly diluted aqueous form, is commonly used in surface preparation procedures.

A further structural examination of the post-exposed contacts reveals the particular nature of the material degradation; revealing that PdGe contacts experience attack at both the GaAs/Ge and PdGe/interconnect interfaces. Bright field TEM images of the contact cross-section shows clear evidence for Ge removal at the GaAs interface (figure 5) and a further formation of voids in the vicinity of the PdGe/interconnect junction (figure 6).

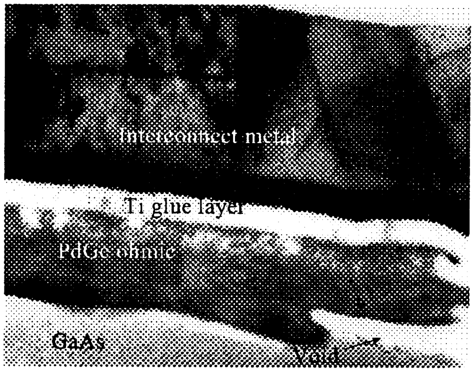

Fig. 5 Void formation at the PdGe/GaAs interface.

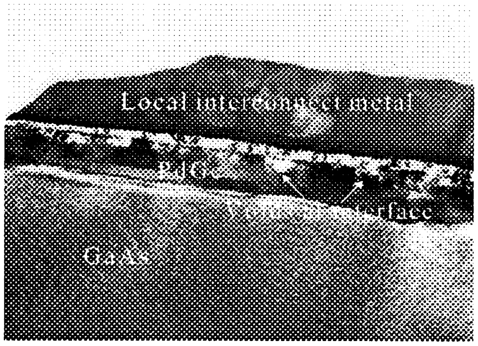

Fig. 6 Void formation at the PdGe/interconnect metal interface

Both areas of materials dissolution are considered to be as a result of an electrochemical attack of the germanium component of the contact but occur as distinctly separate events. The leaching of Ge from PdGe (figure 6) is driven by the contact potential with the overlying interconnect metal and forms a network of smaller voids, which may subsequently coalesce on further thermal treatments. This form of degradation obviously may only occur after contacting the ohmic with the local interconnect metal and as such can be discerned by electrical measurements of TLM structures before and after connecting. Such electrical investigations do support this view of degradation – for both PdGe and to a lesser extent AuGeNi. Conversely, the gross material removal of germanium at the GaAs interface does not require the presence of the overlaying interconnect metal and presents a phenomena not experienced in AuGeNi systems. The resulting contact structure imparts a considerably more severe response to electrochemical attack being exhibited by PdGe based alloyed contacts. The undercutting of alloyed contact not only presents a smaller effective ohmic contact area and hence higher apparent contact resistance, but also creates a re-entrant profile beneath the metal that may harbor residues or potential contamination.

It is thus overly apparent that the successful implementation of PdGe based ohmic contacts requires that a much greater level of chemical or corrosion resistance be afforded to these alloys.

PROTECTION OF PDGE CONTACTS DURING PROCESSING

The protection of the PdGe alloyed contacts was investigated by evaluating different capping schemes. These will be discussed as (i) Dielectric capping, (ii) Thick metal capping and (iii) Thin metal capping. The results of these treatments are summarized as Table 3. (below)

(i) Dielectric capping is a straightforward capping of the ohmic contact after alloying with a silicon nitride overlayer. In this manner, exposure to process chemicals is negated after the alloying until the contact is exposed once more following a plasma etch (to allow the previously described local interconnect to be formed). This readily implementable process step does for the most part afford protection to the covered contacts during the following gate processing steps (see flow schematic). However, it is also apparent that no protection is afforded during both the ohmic and local interconnect metal lift-off steps. Water exposure at either of these steps would thus retain its potential to degrade the PdGe alloy structure. Results on wafer lots protected by the nitride overlayer were consistent with this assumption when subjected to prolonged aqueous exposure at either lift-off step.

(ii) Thick metal capping in this case refers to applying a thick gold capping layer of approximately similar thickness to the underlying PdGe. Unlike the dielectric capping described above, any self-contained capping of the metal layers should afford protection to the underlying Ge at all stages of production. In this experiment we alloyed the resulting metal layers at both above and below the AuGe eutectic temperature (ca. 360C) to differentiate any effects that may arise due to the liquid phase formation and, hence, Ge intermixing with Au. The results of this investigation did, indeed, show that process degradation of the ohmic contacts could be controlled by alloying at temperatures below the AuGe eutectic point. However, the contact resistance values obtained for these 'stable' contacts were in the range of 2-3x the values obtained for AuGeNi 'standard' contacts. By alloying the PdGeAu contacts at a temperature below where we would expect AuGe interaction, the expectation was that PdGe could alloy with the underlying GaAs leaving the Au as an inert capping layer. With measured contact resistance values for this alloy system being consistently 3-4x that of simple PdGe, it is apparent that Au acts as a ternary element in this alloy system. It is the issue of the role of the Au in this alloy system that prompted us to employ a 'thin' metal capping.

(iii) Thin metal capping follows from the previous section and similarly involves providing a protective Au cap. However, in this case the cap is designed to be sufficiently thin as to minimize the effect of the Au ternary element on alloying, yet still maintain an inert barrier for aqueous ingress to the underlying PdGe. For our particular alloy system we found this capping layer to be in the 100-200Å range. Processed wafer lots were found to display contact resistances marginally superior to standard AuGeNi ohmic contacts whilst displaying immunity to aqueous degradation.

TABLE 3.
Evaluation of different capping schemes for PdGe

Alloy System	Relative Contact Resistance	Stability to processing
AuGeNi (standard)	1.0	good
PdGe (nitride capped)	0.6-0.8	poor
PdGeAu Thick Au > 360C	1.0	Very poor
PdGeAu Thick Au < 360C	1.8-2.2	good
PdGeAu Thin Au < 360C	0.9-1.0	good

CONCLUSIONS

PdGe based solid state ohmic contacts can display superior contact resistivities and greater morphological stability when compared to their AuGeNi counterparts. However, their propensity to degrade in common wafer processing media presents challenges to their successful implementation. Capping with inert metal overlayers seems a promising route in achieving this goal as long as overlayer interactions with the PdGe/GaAs alloying process is minimized. Thin gold overlayers may present a simple alternative to other metal capping systems proposed elsewhere.

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