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Novel Nonalloyed Thermally Stable Pd/Sn and Pd/Sn/Au Ohmic Contacts for the Fabrication of GaAs MESFETs

M. S. Islam and Patrick J. McNally

***Abstract*—GaAs metal-semiconductor field-effect transistors (MESFETs) have been fabricated utilizing thermally stable Pd/Sn and Pd/Sn/Au ohmic contacts for the first time. MESFETs with Pd/Ge Oohmic contacts are fabricated for comparison. Thermal stability of the Pd/Sn, Pd/Ge and Pd/Sn/Au ohmic contacts is also presented.**

***Index Terms*—MESFETs, metallization, nonalloyed contacts, ohmic contacts, Pd-based contacts.**

I. Introduction

The performances of GaAs MESFETs depend on the quality of ohmic contacts. As MESFETs dimensions approach the submicrometer regime, the requirements of edge uniformity of ohmic contacts have become crucial. Nonalloyed Pd/Ge ohmic metallizations are used for the fabrication of GaAs MESFETs [1]–[3]. One of the most important criteria for an ohmic contact is its thermal stability. 410 $^\circ$C is a typical temperature for testing the thermal stability of ohmic contacts to GaAs [2]. Thermal stability of the Pd/Ge metallizations at and above 410 $^\circ$C still requires further studies [2], [4].

Novel Pd/Sn and Pd/Sn/Au ohmic metallizations have already been developed for n-GaAs [5]–[7]. In this paper, thermal stability of the Pd/Sn, Pd/Sn/Au and Pd/Ge ohmic contacts at 410 $^\circ$C is presented. GaAs MESFETs have been fabricated utilizing Pd/Sn, Pd/Sn/Au and Pd/Ge ohmic contacts.

II. Experimentals

Ohmic contacts were fabricated on a Si-doped 2×10^{18} cm^{-3}) n-GaAs epitaxial layer grown by MOVPE in a MESFET structure [6]. The cleaning and etching procedures of GaAs substrates were described in [6]. Mesas for the MESFETs and TLM patterns were defined by standard photolithography and lift-off processes.

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TABLE I
THE CALCULATED OPTIMUM ρ_c AND $\Delta\rho_c$ VALUES OF THE OHMIC CONTACTS. ALL CONTACTS ARE ANNEALED FOR 30 MIN

Metallizations	Annealing conditions	Optimum ρ_c (Ω-cm^2)	$\Delta\rho_c$ (Ω-cm^2)
Pd/Sn	330 ^{0}C	2.28×10^{-5}	$\pm0.61\times10^{-5}$
Pd/Sn/Au	300 ^{0}C	8.13×10^{-6}	$\pm0.21\times10^{-6}$
Pd/Ge	330 ^{0}C	2.84×10^{-6}	$\pm0.12\times10^{-6}$

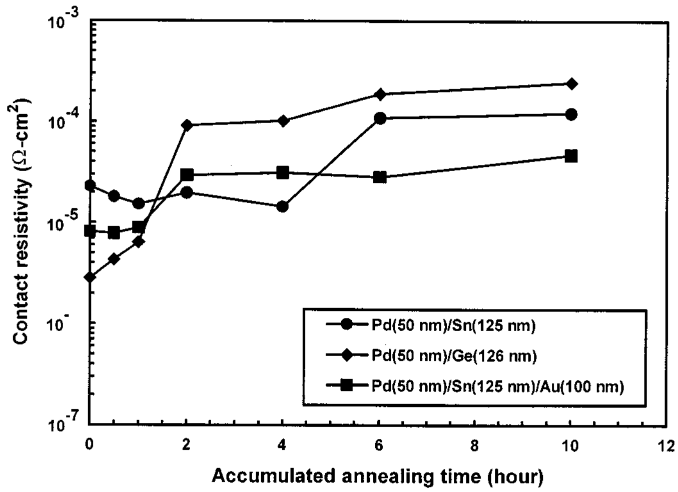


Fig. 1. Thermal stability results for Pd/Sn, Pd/Sn/Au, and Pd/Ge ohmic contacts at 410 $^\circ$C.

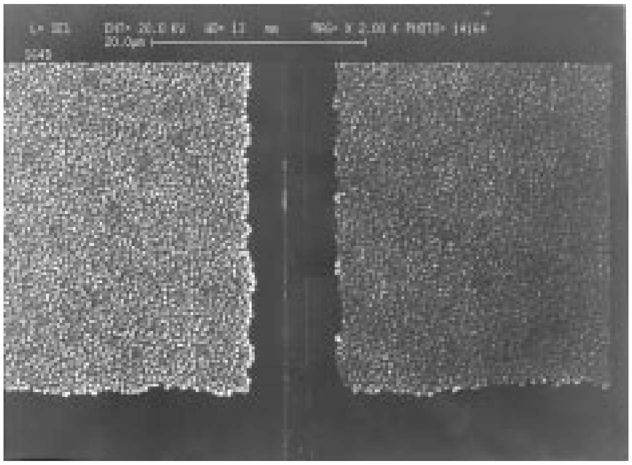
The n-GaAs/Pd(50 nm)/Sn(125 nm), n-GaAs/Pd(50 nm)/Ge(126 nm) and n-GaAs/Pd(50 nm)/Sn(125 nm)/Au(100 nm) samples were prepared by sequential deposition of metallizations in a resistance heating evaporator. The base and evaporation pressures were low 10^{-6} torr. A conventional graphite strip annealer with flowing forming gas was used for the annealing. Annealing cycles for the Pd/Sn, Pd/Sn/Au and Pd/Ge contacts were optimized elsewhere [7], [8].

A recess gate etch was performed between source and drain of the MESFETs. 250 nm Al gate metallizations were evaporated. The base and evaporation pressures were low 10^{-6} torr. The gate-length, L_G, used for the MESFETs were 0.4, 0.6, 0.8, 1.0, and 2.0 μm.

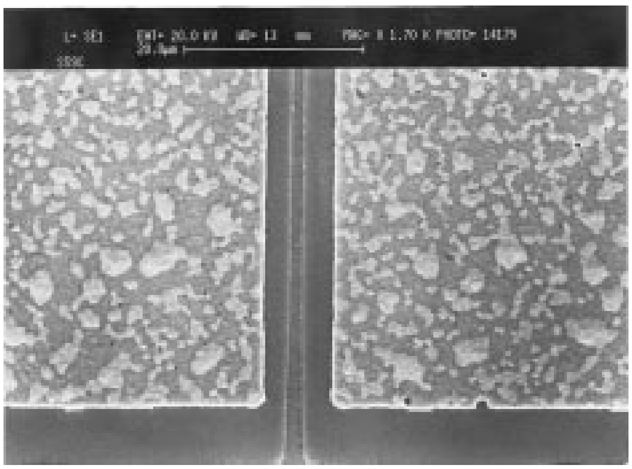
Surface morphology and edge uniformity of the contacts were investigated using a Cambridge S360 SEM. Contact resistivity, ρ_c, were measured utilizing the conventional transmission line model (cTLM) method. The I–V characteristics of the MESFETs were determined using a curve tracer.

III. Results and Discussion

The ρ_c of the contacts are measured using cTLM [9] method. The transfer length method [10] is utilized to measure ρ_c values. Table I summarizes the optimum ρ_c and measurement error, $\Delta\rho_c$, values for the contacts. The Pd/Ge contacts show optimal ρ_c which is approximately one order of magnitude lower than that of the Pd/Sn contacts. The Pd/Sn/Au contacts show optimum ρ_c of $8.13\times10^{-6}\Omega$-cm^2 at 300°C. The Pd/Ge contacts show excellent reproducibility. However, the reproducibility of the Pd/Sn/Au metallizations is comparable to that of the Pd/Ge contacts.



(a)



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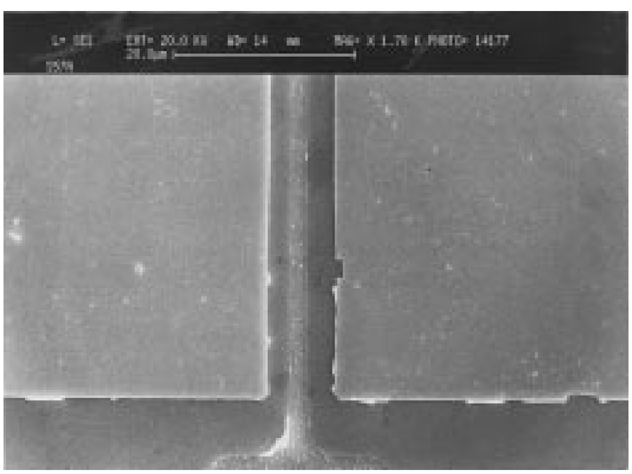
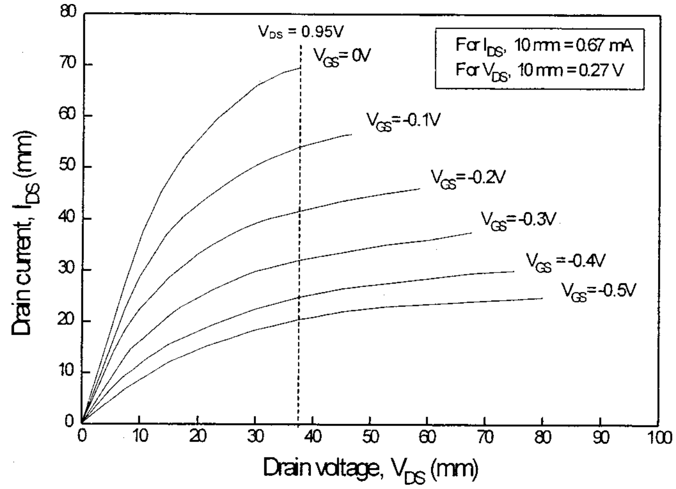
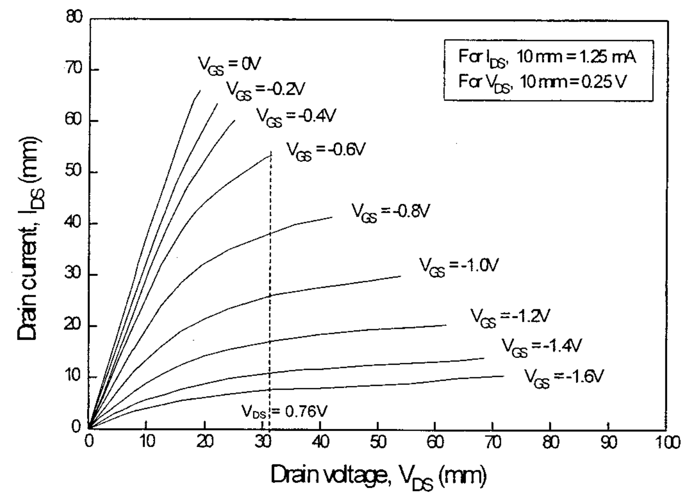


(c)

Fig. 2. SEM micrographs showing surface morphology and edge uniformity for (a) Pd/Sn, (b) Pd/Sn/Au, and (c) Pd/Ge ohmic contacts at optimal annealing temperatures.



(a)



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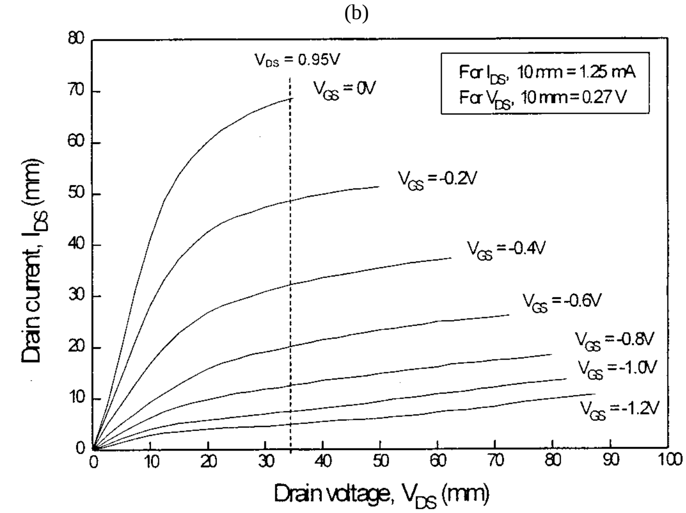

(c)

Fig. 3. *I–V* characteristics of the GaAs MESFETs associated with (a) Pd/Sn, (b) Pd/Sn/Au, and (c) Pd/Ge source/drain ohmic contacts.

Data for thermal stability measurements of the contacts are shown in Fig. 1. The average ρ_c values of 4 TLM patterns are presented. The zero accumulated annealing time value of ρ_c indicates optimum ρ_c values of Table I. It is evident that both Pd/Sn and Pd/Sn/Au contacts display better thermal stability at 410 °C when compared to the Pd/Ge metallizations.

For the MESFETs, the dimensions of the source and drain ohmic pads were 100 μm square. All MESFETs operated in depletion mode. Due to the lift-off problem in gate level, MESFETs with L_G =0.4, 0.6, 0.8, and 1.0 μm could not be realized in this paper. In order to get rid of this problem, electron-beam evaporation is recommended for the gate metallization. MESFETs with $L_G = 2\,\mu$m were investigated in this study.

Fig. 2 shows the edge uniformity and surface morphology of source/drain ohmic contacts at the optimum ρ_c conditions. Surface morphology of the Pd/Sn/Au metallizations is better than that of the Pd/Sn contacts and is comparable to the Pd/Ge contacts. The contact edges are poor for the Pd/Sn metallizations. Although the edge uniformity for the Pd/Ge contact is very good and the undulation is virtually impossible to measure, this metallization system exhibits a slight lift-off problem [Fig. 2(c)].

Fig. 3 displays the current–voltage (*I*–*V*) characteristics of the MESFETs. The calculated g_m for the MESFETs with Pd/Sn ohmic contacts is 107 mS/mm [Fig. 3(a)]. Due to the difficulty of viewing I–V characteristics at $V_{GS} = 0$ V in the saturation region for the MESFETs with Pd/Sn/Au metallizations, g_m is calculated at $V_{GS} = -0.8$ V and $V_{DS} = 0.76$ V [Fig. 3(b)] which is 100 mS/mm. Generally, maximum g_m (g_{max}) occurs around $V_{GS} = 0$ V. Therefore, g_{max} for this MESFET would be greater than 100 mS/mm. It is evident that the MESFETs with Pd/Sn/Au metallization display improved g_m when compared to the Pd/Sn contact. The calculated $g_{\max}$ for the MESFETs with Pd/Ge contacts are 130 mS/mm [at $V_{GS} = -0.2$ V and $V_{DS} = 0.95$ V, Fig. 3(c)] and 44 mS/mm [at $V_{GS} = -0.8$ V and $V_{DS} = 0.95$ V]. The latter g_m is lower than that for the Pd/Sn/Au contacts ($g_m = 100$ mS/mm). Therefore, MESFETs with improved g_m can be fabricated utilizing novel thermally stable Pd/Sn/Au ohmic contacts.

IV. Conclusions

Although Pd/Ge contacts display optimum ρ_c which is better than those of Pd/Sn and Pd/Sn/Au metallizations, the later contacts exhibit improved thermal stability at 410 °C. MESFETs with Pd/Sn/Au metallizations show improved characteristics compared to Pd/Sn and Pd/Ge contacts. The edge uniformity of source/drain contacts with Pd/Sn/Au metallizations is better than that of the Pd/Sn metallizations and is comparable to that of the Pd/Ge metallizations. However, Pd/Ge contacts tend to exhibit imperfect metal lift-off. Therefore, novel thermally stable Pd/Sn/Au ohmic contacts provide promising candidates for future GaAs devices.

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