In-situ Iridium Refractory Ohmic Contacts to p-InGaAs

Ashish Baraskar[1], Vibhor Jain[1], Mark A. Wistey[3], Evan Lobisser[1], Brian J. Thibeault[1], Arthur C. Gossard[1,2] and Mark J. W. Rodwell[1]
[1]ECE and [2]Materials Departments, University of California, Santa Barbara, CA, USA
[3]Electrical Engineering, University of Notre Dame, IN, USA

Very low resistance metal-semiconductor contacts are crucial for the performance of transistors in THz bandwidths. The base and emitter contact resistivities (ρ_c) in heterojunction bipolar transistors (HBTs) must decrease in proportion to the inverse square of the transistor cutoff frequency [1, 2]. A ρ_c of less than 1×10^{-8} Ω-cm^2 is required for III-V HBTs and FETs for having simultaneous 1.5 THz f_t and f_{max} [1, 2]. Ohmic contacts to p-type $In_{0.53}Ga_{0.47}As$ have been studied extensively because of its application as the base contacts in InP based HBTs. *Ex-situ* Pd/Ti/Pd/Au contacts have shown ρ_c = 4×10^{-8} Ω-cm^2 to p-$In_{0.53}Ga_{0.47}As$ [3, 4], but penetrates into the semiconductor by combined chemical reaction and diffusion [5]. Low resistivity, thermally stable contacts having < 5 nm metal penetration depth are required for HBTs having < 20 nm thick base layers. Here we report $\rho_c = (5.8 \pm 4.8)\times10^{-9}$ Ω-cm^2 for in-situ, refractory Ir contacts to p-type $In_{0.53}Ga_{0.47}As$.

The semiconductor epilayers were grown by solid source MBE. A 100 nm undoped $In_{0.52}Al_{0.48}As$ layer was grown on a semi-insulating InP (100) substrate, followed by 100 nm of carbon doped $In_{0.53}Ga_{0.47}As$, using CBr_4 as the dopant source. The $In_{0.53}Ga_{0.47}As$ layer was grown at 350 ^{o}C substrate temperature and a 7:1 group V to group III ratio. Ir (20 nm) and Mo (20 nm) were deposited *in-situ* on half the wafer surface in an electron beam evaporator attached to the MBE chamber under ultra high vacuum (UHV). Hall measurements were done on the samples not coated with Ir/Mo. Samples coated with Ir/Mo were processed into transmission line model (TLM) structures for contact resistance measurement. Ti (20 nm)/Au (500 nm)/Ni (50 nm) contact pads were patterned on the samples using photolithography and lift-off after an e-beam deposition. Mo was then dry etched in an SF_6/Ar plasma using Ni as a mask. The TLM structures were then isolated using mesas formed by photolithography and a subsequent wet etching with 1:1:25:H_3PO_4:H_2O_2:DI water. Resistances were measured by four-point (Kelvin) probing. The processed samples were annealed under nitrogen atmosphere at 250 ^{o}C for 60 minutes, replicating the thermal cycle experienced by a base contact during transistor fabrication.

As determined through Hall measurements, the highest hole concentration (p) achieved was 2.2×10^{20} cm^{-3} exhibiting a mobility (μ) and sheet resistance (R_{sh}) of 29.9 cm^2/Vs and 94 Ω, respectively. The ρ_c achieved for the sample with 2.2×10^{20} cm^{-3} holes was $(5.8 \pm 4.8)\times10^{-9}$ Ω-cm^2, which is the lowest reported to date for ohmic contacts to p-type InGaAs. The sheet resistivity determined from TLM measurements was 99 Ω, correlating closely to the sheet resistivity obtained with Hall measurements. The annealed samples show a ρ_c of $(8.0 \pm 5.6)\times10^{-9}$ Ω-cm^2, differing from the un-annealed samples by less than the margin of error in measurement.

Given the low ρ_c and demonstrated thermal stability, in-situ Ir is a strong candidate for base ohmic contacts in THz HBTs.

1. M. J. W. Rodwell, M. L. Le, B. Brar, IEEE Proceedings, Volume 96, Issue 2, Feb. 2008, pp 271 - 286.
2. M. J. W Rodwell et al., Proceedings, IEEE Compound Semiconductor Integrated Circuit Symposium, 2008.
3. Z. Griffith, M.J.W. Rodwell, M. Dahlström, X.-M. Fang, D. Lubyshev, Y. Wu, J.M. Fastenau and W.K. Liu, 2005 IEEE/OSA Conference on Indium Phosphide and Related Materials, May 8-12, Glasgow.
4. Vibhor Jain, Evan Lobisser, Ashish Baraskar, Brian J. Thibeault, Mark Rodwell, Z Griffith, M Urteaga, S. T. Bartsch, D. Loubychev, A. Snyder, Y. Wu, J. M. Fastenau, W.K. Liu, 2010 IEEE Device Research Conference, June 21-23, South Bend, IN.
5. E.F Chor, D. Zhang, H. Gong, W.K. Chong, S.Y. Ong, J. of App. Phys., **87**, 5, 2437-2444 (2000).

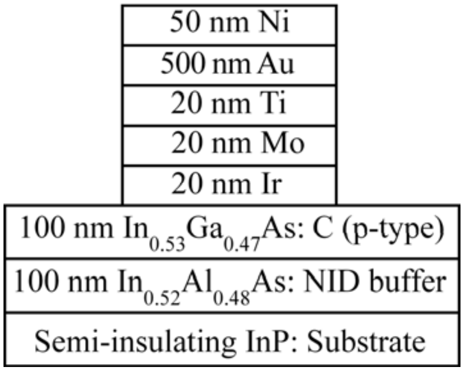

Fig 1: Cross-section schematic of the metal-semiconductor contact layer structure. Ir/Mo were deposited in an electron beam deposition system connected to MBE system under ultra high vacuum.

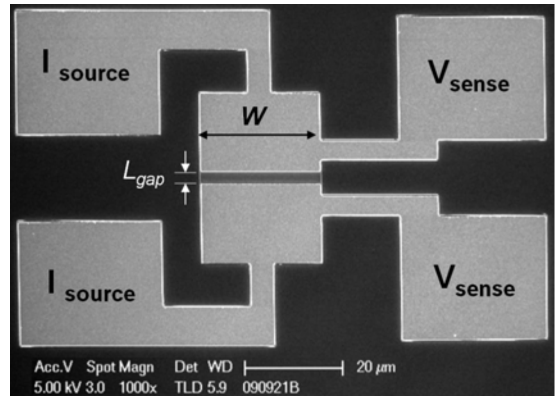

Fig 2: Scanning electron micrograph of the TLM pattern used for the contact resistivity (ρ_c) measurement. Separate pads were used for current biasing and voltage measurement.

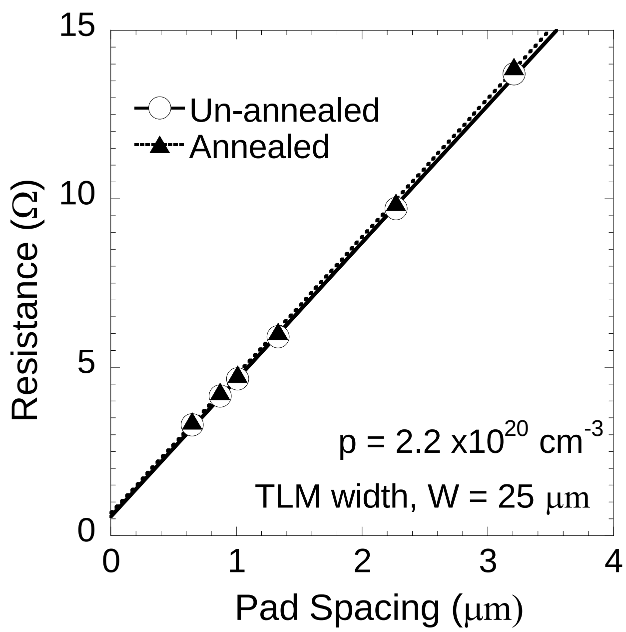

Fig 3: Measured TLM resistance as a function of pad spacing for un-annealed and annealed Ir contacts on p-InGaAs.

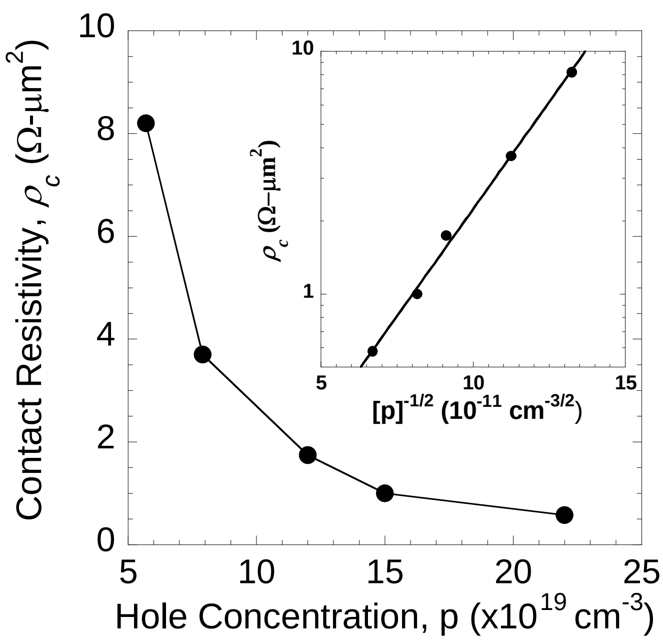

Fig. 4: Variation of contact resistivity (ρ_c) with hole concentration. Inset: Exponential dependence of ρ_c on $(p)^{-1/2}$ indicating tunneling behavior of the contacts.