In-situ Ohmic contacts to p-InGaAs

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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 $1\text{x}10^{-8}$ 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. Pd has shown ρ_c = 6.3 x 10^{-8} Ω-cm^2 to p-InGaAs [3], but penetrates into the semiconductor by combined chemical reaction and diffusion [4]. Low resistivity, thermally stable contacts having < 5 nm metal penetration depth are required for HBTs having < 20 nm thick base layers. Here we report $\rho_c = (2.0 \pm 0.8)\times10^{-8}$ Ω-cm^2 for in-situ Mo 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 $In_{0.53}Ga_{0.47}As$. 20 nm of Mo was deposited in an electron beam evaporator attached to the MBE chamber under ultra high vacuum. Mo was deposited on half of the surface of the samples using a shadow mask. Hall measurements were done on the samples not coated with Mo. Samples coated with 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. Resistances were measured by four-point (Kelvin) probing. The processed samples were annealed under nitrogen atmosphere at 250 ^oC for 120 minutes, replicating the thermal cycle experienced by a base contact during transistor fabrication.

The ρ_c achieved for the un-annealed samples was $(2.0 \pm 0.8)\times10^{-8}$ Ω-cm^2, which is the lowest reported to date for Ohmic contacts to p-type InGaAs. As determined through Hall measurements, the active carrier concentration, mobility and sheet resistance was 1.1×10^{20} cm^{-3}, 39.6 cm^2/Vs and 150 $\Omega/\square$, respectively. The annealed samples show a ρ_c of $(2.5 \pm 0.9)\times10^{-8}$ Ω-cm^2. TEM images of the annealed samples show a uniform and abrupt Mo-InGaAs interface, indicating minimal intermixing of the metal semiconductor layers. We speculate that the increase in ρ_c upon annealing may be due to the presence of an interfacial carbon layer which degrades upon annealing. Although ρ_c increases to $(2.5 \pm 0.9)\times10^{-8}$ Ω-cm^2 upon annealing, in-situ Mo remains a strong candidate for base Ohmic contacts in THz HBTs.

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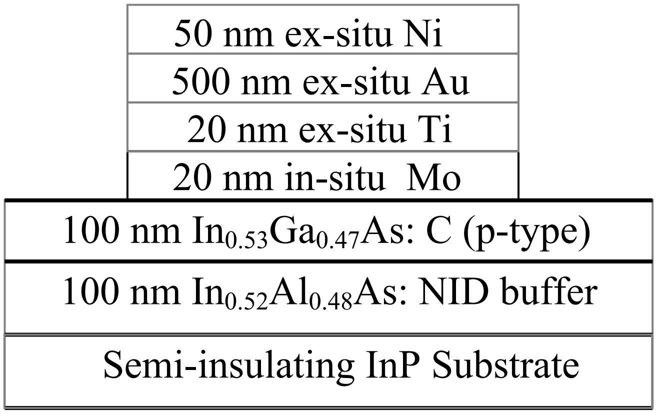

Fig 1: Cross-section schematic of the metal-semiconductor contact layer structure. Mo was deposited in an electron beam deposition system connected to MBE system under ultra high vacuum.

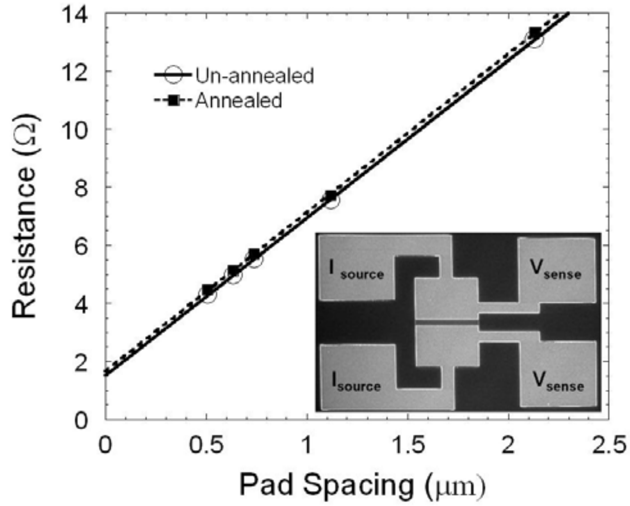

Fig 2: Measured TLM resistance as a function of pad spacing for un-annealed and annealed Mo contacts on p-InGaAs. Inset: Schematic of the TLM pattern used for the contact resistivity (ρ_c) measurement. Separate pads were used for current biasing and voltage measurement.

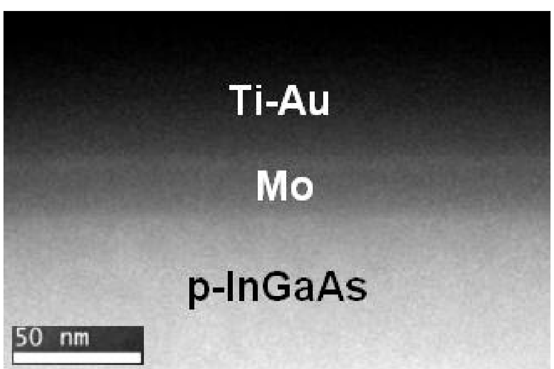

Fig 3: Transmission electron microscope (TEM) cross section of the Mo/Ti/Au metal contact for the samples annealed at 250 ^{o}C for 120 minutes.