High doping effects on the in-situ and ex-situ ohmic contacts to n-InGaAs
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With the continued scaling of transistors for high-speed performance, achieving very low resistance metal-semiconductor contacts becomes crucial. The base and emitter contact resistivities in heterojunction bipolar transistors (HBTs) must decrease in proportion to the inverse square of the transistor cutoff frequency [1, 2]. A contact resistivity of less than 1x10⁻⁸ Ω-cm² is required for III-V HBTs and FETs for having simultaneous 1.5 THz ft and fmax [1, 2]. High electron velocities in InGaAs enable wide-bandwidth electron devices [3, 4], but lower-resistance ohmic contacts to InGaAs are needed.

Here we report the effect of high doping on the contact resistance of in-situ and ex-situ ohmic contacts to n-type In₀.₅₃Ga₀.₄₇As, lattice matched to InP. A 150 nm In₀.₅₂Al₀.₄₈As layer was grown by solid source molecular beam epitaxy (MBE) on semi-insulating InP (100), followed by 100 nm of silicon doped In₀.₅₃Ga₀.₄₇As. Without breaking vacuum, 20 nm of Mo was deposited on half of each sample using a shadow mask. Hall measurements were done on the bare InGaAs surfaces. All the samples were then processed into transmission line model (TLM) structures for contact resistance measurement. Ti/Au/Ni contact pads were patterned on the samples coated with Mo, whereas Ti/TiW/Ti/Au/Ni contact pads were patterned on the samples with bare InGaAs surface using i-line optical photolithography and lift-off. Mo and Ti/TiW were then dry etched in SF₆/Ar plasma using Ni as etch mask. A four-point probe technique was used to measure resistances using an Agilent 4155C semiconductor parameter analyzer.

Experimental results show that the contact resistance of in-situ Mo and ex-situ Ti/TiW ohmic contacts on n-InGaAs get better if the total number of dopants is increased, even though the number of active carriers remains constant. This is evident from the lowest contact resistance achieved for in-situ Mo contacts ((4.7 ± 2.5) x10⁻⁹ Ω-cm²) and ex-situ Ti/TiW contacts ((7.6 ± 3.5) x10⁻⁹ Ω-cm²) for samples with 1.5x10²⁰ cm⁻³ total Si dopants but with 5x10¹⁹ cm⁻³ active carriers. This contact resistance is lower than that obtained with samples with lower total Si dopants (1x10²⁰ cm⁻³) but with similar (5x10¹⁹ cm⁻³) active carrier concentrations. We speculate that the reduction in contact resistivity is due to filling of additional surface states that are below the level of the donor band, by dopants which do not donate electrons in bulk material but do donate to lower energy surface states. Additional ionized donors reduce the Schottky barrier to electrons.

Although we observe a decrease in active carrier concentration as Si atomic concentration is increased above 1x10²⁰ cm⁻³, the contact resistivity continues to decrease, as would be expected from decreased surface depletion depth from an increased ionized carrier concentration. This data strongly suggests that Si may not be amphoteric at Si concentrations below 1.5x10²⁰ cm⁻³.

Fig 1: Cross-section schematic of the metal-semiconductor contact layer structure (not to scale); (a) in-situ InGaAs/Mo contact, (b) ex-situ InGaAs/Ti/TiW contact. The Mo was deposited in an electron beam deposition system connected to MBE under ultra high vacuum. Ti/TiW is sputtered ex situ for the InGaAs/Ti/TiW contact.

Fig 2: Measured TLM resistance as a function of pad spacing for in-situ Molybdenum and ex-situ Ti/TiW ohmic contacts on n-InGaAs. The inset plots measured TLM resistance vs. pad spacing ranging from 0.8 µm to 27 µm.

Fig 3: Variation of contact resistivity and number of active carriers with total number of Si dopants. The contact resistivity continues to drop with the increase in total Si dopants even though the number of active carriers remains almost constant.