High doping effects on the in-situ and ex-situ ohmic contacts to n-InGaAs

Ashish K. Baraskar[1], Mark A. Wistey[1,2], Vibhor Jain[1], Uttam Singisetti[1], Greg Burek[1], Brian J. Thibeault[1], Yong J. Lee[3], 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]Intel Corporation, Technology Manufacturing Group, Santa Clara, CA

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 -cm^2 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 $In_{0.53}Ga_{0.47}As$, lattice matched to InP. A 150 nm $In_{0.52}Al_{0.48}As$ layer was grown by solid source molecular beam epitaxy (MBE) on semi-insulating InP (100), followed by 100 nm of silicon doped $In_{0.53}Ga_{0.47}As$. 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 SF_6/Ar plasma using Ni as etch mask. A four-point probe technique was used to measure resistances using an Agilent 4155C semiconductor parameter analyzer.

The lowest contact resistance achieved for both in-situ Mo and ex-situ Ti/TiW contacts is 2.0 ± 0.4 x10^{-8} Ω-cm^2 for samples with $5x10^{19}$ cm^{-3} active carriers. The low contact resistance can be attributed to the lack of oxygen, and hence reduced number of oxide surface states, at the metal semiconductor interface due to in-situ deposition of Mo contacts and the oxygen gettering property of titanium. The in-situ Mo contacts were found to remain stable, maintaining a low contact resistance on annealing at 300 ^{o}C and 400 ^{o}C for 1 minute duration. The ex-situ Ti/TiW contacts however show a two fold increase in contact resistance on annealing beyond 300 ^{o}C. Experimental results also 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 active carriers is increased. The contact resistance of 2.0 ± 0.4 x10^{-8} Ω-cm^2 for samples with $5x10^{19}$ cm^{-3} active carriers is much smaller than the contact resistance of 1.5 ± 0.3 x10^{-7} Ω-cm^2 obtained for in-situ Mo contacts and 1.1 ± 0.2 x10^{-7} Ω-cm^2 for ex-situ Ti/TiW contacts, both having $1x10^{19}$ cm^{-3} active carriers. This drop in the contact resistance can be attributed to the improved tunneling through the potential barrier at the metal-semiconductor interface.

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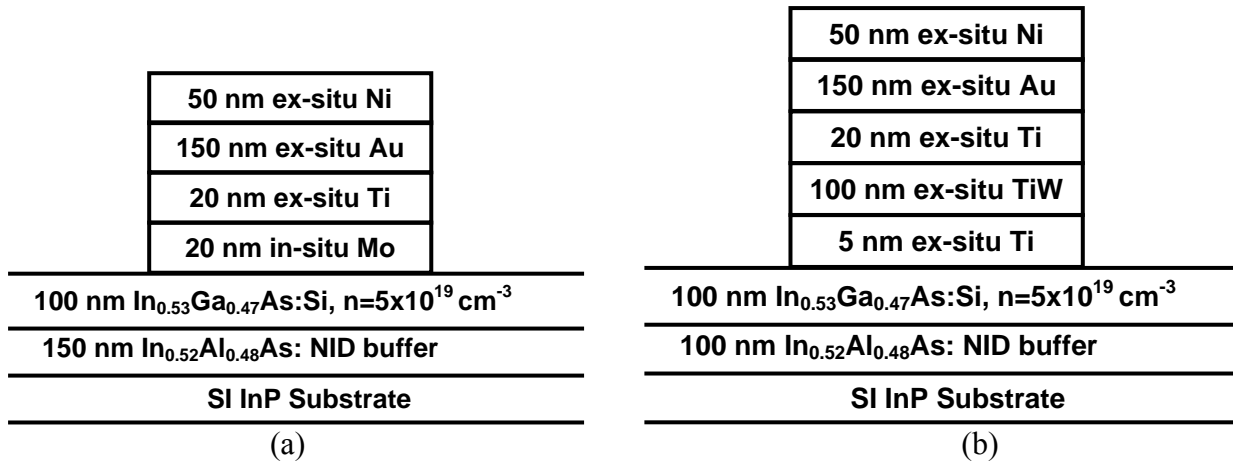5] G. Stareev, H. Künzel, and G. Dortmann, *J. Appl. Phys.*, **74**, 7344 (1993).

| 50 nm ex-situ Ni |
| 150 nm ex-situ Au |
| 20 nm ex-situ Ti |
| 20 nm in-situ Mo |

100 nm In$_{0.53}$Ga$_{0.47}$As:Si, n=5x10^{19} cm^{-3}

150 nm In$_{0.52}$Al$_{0.48}$As: NID buffer

SI InP Substrate

(a)

| 50 nm ex-situ Ni |
| 150 nm ex-situ Au |
| 20 nm ex-situ Ti |
| 100 nm ex-situ TiW |
| 5 nm ex-situ Ti |

100 nm In$_{0.53}$Ga$_{0.47}$As:Si, n=5x10^{19} cm^{-3}

100 nm In$_{0.52}$Al$_{0.48}$As: NID buffer

SI InP Substrate

(b)

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.
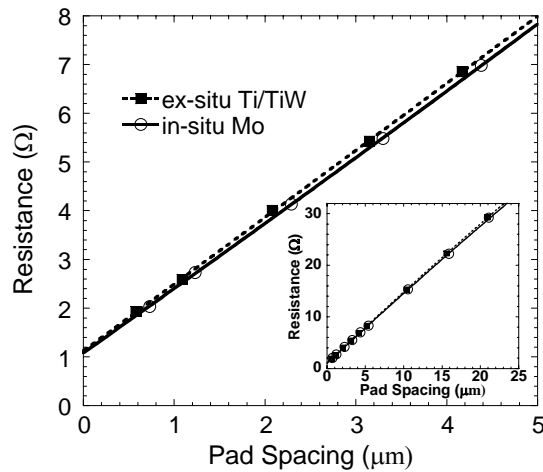

Fig 2: Measured TLM resistance as a function of pad spacing for in-situ Molybdenum and ex-situ Ti/TiW ohmic contacts on n-InGaAs. The inset plots measured TLM resistance vs. pad spacing ranging from 0.8 μm to 27 μm.
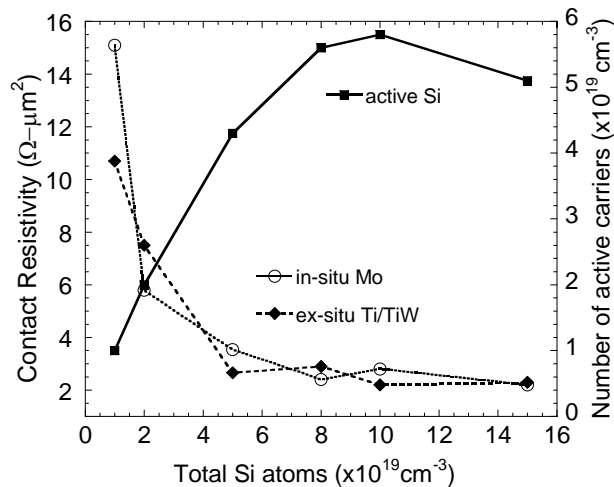

Fig 3: Variation of contact resistivity and number of active carriers with total number of Si dopants. The contact resistivity continues to drop with the increase in total Si dopants even though the number of active carriers remains almost constant.