Ex-situ Ohmic Contacts to n-InGaAs Prepared by Atomic Hydrogen Cleaning

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Transistors in THz bandwidth regimes require low resistance metal-semiconductor contacts. III-V HBTs and FETs necessitate a specific contact resistivity (ρ_c) of less than $1x10^{-8}$ Ω-cm^2 for having simultaneous 1.5 THz f_t and f_{max} [1], [2]. Contact resistivity strongly depends on semiconductor surface preparation prior to metal deposition [3]. In-situ metal deposition technique results in ultra low-resistance ohmic contacts (ρ_c =(1.1±0.6)x10^{-8} Ω-cm^2) [4] but obtaining ρ_c<1x10^{-8} Ω-cm^2 through ex-situ techniques requires significant attention to removal of semiconductor surface oxides. The use of atomic hydrogen has proved to be a potential surface cleaning technique for preparing clean III–V semiconductor surfaces [5]. This work investigates the application of atomic hydrogen cleaning for preparing ex-situ molybdenum (Mo) ohmic contacts to n-type $In_{0.53}Ga_{0.47}As$. A comparison with the contact resistivity obtained with contacts formed directly after surface preparation with 1:10 HCl:H_2O etch is also presented.

The n-type (Si doped) $In_{0.53}Ga_{0.47}As$ films were grown by solid source Molecular Beam Epitaxy (MBE) system on semi-insulating InP (100) substrates. The $In_{0.53}Ga_{0.47}As$ layer had an electron concentration (n) and mobility (μ) of 5x10^{19} cm^{-3} and 870 cm^2/Vs, respectively as determined from Hall measurements. To permit the surface to oxidize, as would occur during normal device processing, the samples were removed from vacuum. The samples were then exposed to UV-ozone for 30 minutes and then treated with 1:10 HCl:H_2O and a DI rinse for 1 minute each. One set of samples were loaded in the MBE chamber where hydrogen cleaning was carried out at 420 ^{o}C for 40 minutes. Reflection High Energy Electron Diffraction (RHEED) patterns were recorded along [110] and $[\bar{1}10]$ azimuths after the hydrogen cleaning process. The RHEED pattern showed a clear (4x2) reconstruction, indicating a clean surface. 20 nm of molybdenum (Mo) was then deposited in an electron beam deposition system connected to MBE under ultra high vacuum. The other set of samples were loaded in the sputter chamber directly after 1:10 HCl:H_2O etch for contact metal deposition. Both set of samples were then processed into Transmission Line Model (TLM) structures for contact resistance measurement. A dry etch mask of Ti/Au/Ni was deposited by e-beam evaporation and lifted off to define transmission line model (TLM) pads. Mo was etched with SF_6/Ar using inductively coupled plasma. A wet etch isolated the TLM patterns. TLM pad spacings from 0.6-25 μm were verified using scanning electron microscopy. Four point measurements reduced parasitic resistances. The samples were rapid thermal annealed for 60 sec at 250-400 °C in N_2.

The lowest specific contact resistivity achieved for atomic hydrogen cleaned samples was **(1.3±0.7)x10^{-8}** Ω-cm^2, which is the lowest ever reported for ex-situ contacts to n-type $In_{0.53}Ga_{0.47}As$. It is comparable to the contact resistivity of (1.1±0.6)x10^{-8} Ω-cm^2 obtained for in-situ Mo contacts to n-type $In_{0.53}Ga_{0.47}As$ reported in ref. [4]. It is also smaller than the contact resistivity obtained for samples prepared with HCl cleaning ((ρ_c=2.3±1.0)x10^{-8} Ω-cm^2). All the contacts were found to remain stable, maintaining a low contact resistivity on annealing to at least 400 ^{o}C. The low contact resistivity (ρ_c=**(1.3±0.7)x10^{-8}** Ω-cm^2) clearly shows the effectiveness of atomic hydrogen in removing surface oxides and contaminants as compared to wet chemical etching. This technique (atomic hydrogen cleaning) could certainly benefit the ohmic contacts based on ex-situ techniques, such as are required for any device contacts formed after the initial crystal growth.

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3. Vibhor Jain, Ashish K. Baraskar, Mark A. Wistey, Uttam Singisetti, Zach Griffith, Evan Lobisser, Brian J. Thibeault, Arthur C. Gossard, and Mark. J. W. Rodwell, 21th IEEE International Conference on Indium Phosphide and Related Materials, 10–14 May 2009, pp. 358–361.
4. Ashish Baraskar, Mark A. Wistey, Vibhor Jain, Uttam Singisetti, Greg Burek, Brian Thibeault, Yong Ju Lee, Arthur Gossard and Mark Rodwell, J. Vac. Sci. Tech. B **27**, 2036 (2009)
5. Khatiri et. al., Surface Science **548** (2004) L1–L6

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Supporting information for abstract titled **“Ex-situ Ohmic Contacts to n-InGaAs Prepared by Atomic Hydrogen Cleaning”**

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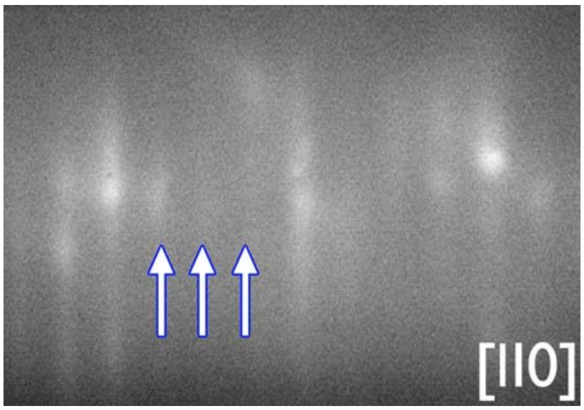

Fig. 1: RHEED pattern of the sample after hydrogen cleaning. The 4x reconstruction is clearly visible along the [110] azimuth.

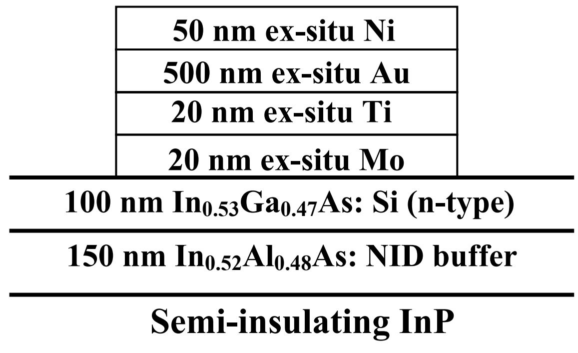

Fig. 2: Cross-section schematic of the metal-semiconductor contact layer structure used for TLM measurements.

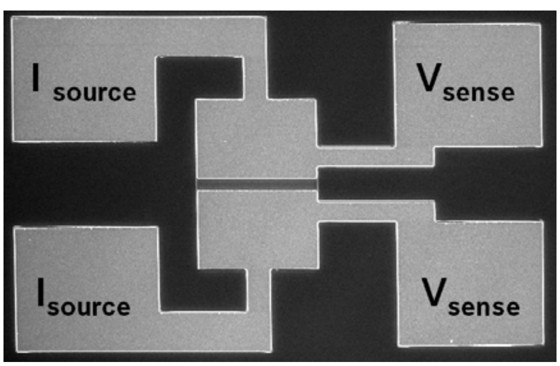

Fig. 3: Schematic of the TLM pattern used for the contact resistivity measurement. Separate pads were used for current biasing and voltage measurement

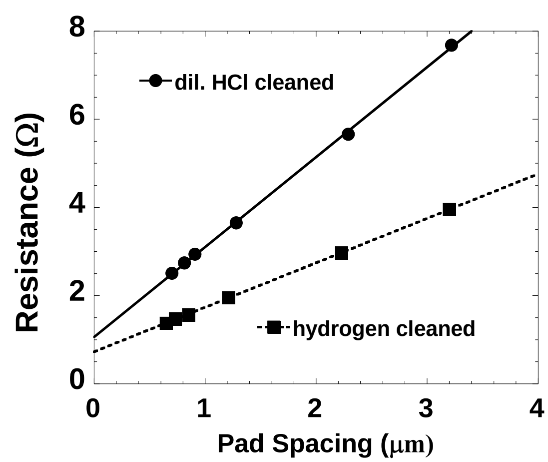

Fig. 4: Measured TLM resistance as a function of pad spacing for ex-situ molybdenum ohmic contacts on n-$In_{0.53}Ga_{0.47}As$.

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