Title: Regrowth of Self-Aligned, Ultra Low Resistance Ohmic Contacts on InGaAs

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Introduction:

Doubling the bandwidth of an electronic device requires reducing contact resistance by a factor of 4. THz transistors therefore need contact resistance below 10^{-8} Ω-cm^2, a factor of five lower than state of the art in III-V's. Molecular beam epitaxy (MBE) can make low-resistance contacts by enabling doping levels well above thermodynamic limits. But MBE is a blanket deposition process, while contacts are often constrained to well-defined areas close to the working device. Contacts often need to be made to lightly-doped layers, necessitating regrowth for higher doping. Selective epitaxy and regrowth through (e.g.) patterned windows can address these difficulties, but these have historically been troublesome in MBE. We present a combined process flow (Fig. 1) which allows effectively self-aligned MBE regrowth.

Methods:

A MOSFET gate was defined lithographically on n++ InGaAs lattice matched to InP. 20nm SiN_x sidewalls were deposited to encapsulate metals. To clean the InGaAs surface, the wafer was exposed to UV ozone to remove trace organics and to create a 2 nm layer of sacrificial surface oxide. This was followed by a 60 second 1:10 HCl:H_2O dip and rinse to remove oxides and trace metals. The wafer was immediately placed in UHV and baked overnight. Before regrowth, the wafer was exposed to 10^{-6} Torr of in-situ, thermally cracked H_2 for 1 hour at 350 °C. The wafer was then loaded into the growth chamber, and 50nm of additional InGaAs:Si was grown, followed by 20nm of in-situ, e-beam Mo for contacts.

The wafer was then unloaded again for planarization and etchback. Thick photoresist was spun on, burying the 300nm tall gates, then etched back uniformly to expose the gate, including InGaAs and Mo overgrowth. These were etched, removing all overgrowth from the gate and sidewalls. This left n++ InGaAs immediately adjacent to the gate on both sides, separated from the channel only by the thickness of the SiN_x sidewalls on the gate.

Results:

RHEED showed a clear (2x4) reconstruction throughout regrowth (Fig. 2). High resolution transmission electron microscopy (TEM, not shown) revealed no visible interface layer. Transmission line measurements (TLM) showed contact resistivity of 1.3×10^{-8} ohm-cm^2 (Fig. 3), which is comparable with $0.5\text{-}0.9\times10^{-8}$ ohm-cm^2 for non-regrowth samples. These techniques are applicable to many other electronic and optoelectronic devices as well.

Conclusion:

Careful surface cleaning plus planarization/etchback enables self-aligned, ultra-low resistance ohmic contacts on transistors by MBE. Selective area growth with horizontal dimensions of nanometers can be realized by normal MBE. Even processed, regrown InGaAs showed contact resistance well below that of published, state of the art contacts.

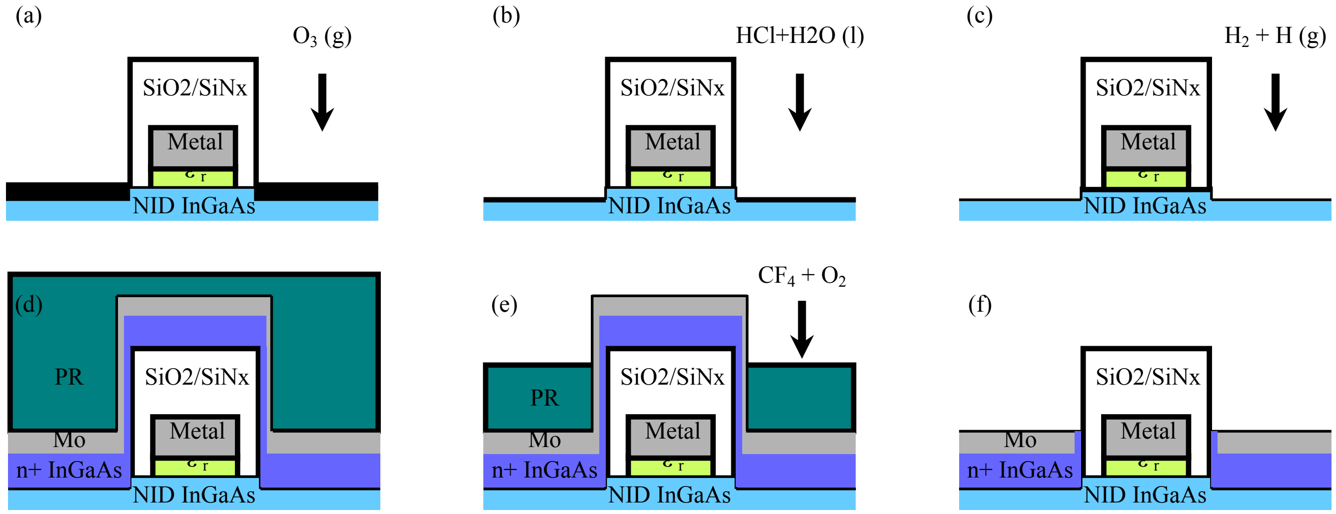

Fig. 1. Self-aligned MBE regrowth process flow (not to scale). (a) UV ozone. (b) HCl:H2O 1:10. (c) Atomic hydrogen. (d) Regrowth and planarization. (e) Etchback. (f) Etch InGaAs and Mo, strip resist.

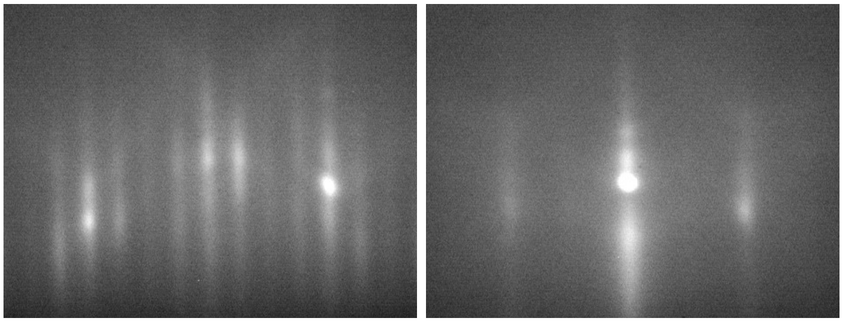

Fig. 2. RHEED diffraction pattern (4x2) after hydrogen clean.

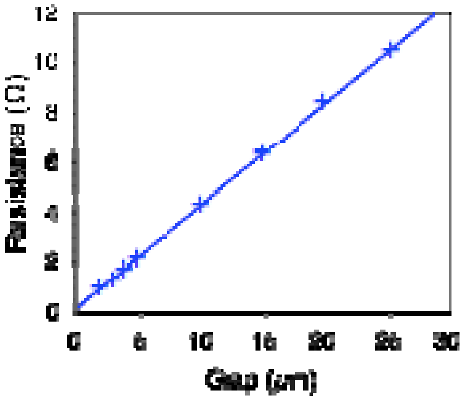

Fig. 3. TLM of regrown processed contacts.