MBE Growth of ErAs/In(Ga)As Epitaxial Ultra-Low Resistance Ohmic Contacts

S. R. Bank, U. Singisetti, A. M. Crook, J. D. Zimmerman, J. M. O. Zide, A. C. Gossard, and M. J. W. Rodwell
ECE and Materials Departments, University of California, Santa Barbara, CA 93106
Phone: (805) 893-7065, Fax: (805) 893-8486, Email: sbank@ece.ucsb.edu

As InGaAs/InP heterojunction bipolar transistors (HBT) are scaled towards terahertz cutoff frequencies, the emitter Ohmic contact resistance has become the main impediment to achieving higher frequency operation. To double the speed of an HBT, transit times are halved by reducing layer thicknesses by a factor of two.[1] To compensate for the resulting two-fold increase in capacitances and to halve the RC time constants, contact resistances must therefore decrease by a factor of *four*. In the past, this has been accomplished by increasing doping levels, improving surface preparation procedures, and employing reactive metallization and sophisticated annealing schemes. This approach is fundamentally empirical and progress is uncertain. Moreover, *ex situ* contact formation is especially sensitive to process variations and this approach is reaching its ultimate limits.

We present a new approach to forming ultra-low resistance Ohmic contacts to III-V semiconductors. It is well established that semimetallic rare earth pnictides, such as ErAs, can be grown epitaxially on III-V semiconductors such as (In,Ga)As.[2] The interface exhibits a perfect continuous arsenic sublattice, despite the differing crystal structures, and no broken bonds are observed at the interface.[3] Based upon previous Schottky barrier height measurements[4] of ErAs/InAlGaAs diodes grown on InP and accounting for strain effects, we estimate that the Fermi level of ErAs should align ~100 meV above the conduction band of InAs, as shown in Fig. 1. Moreover, the emitter contact may be grown by MBE during the initial epitaxial step without exposing the semiconductor surface to atmosphere. This results in an almost perfect Ohmic contact. In concert with epitaxial regrowth, this approach may also be applied to base and collector contacts.

To demonstrate this approach, samples were grown by solid-source MBE and processed into transmission line (TLM) structures for contact resistance measurements. An undoped 1000 Å $In_{0.52}Al_{0.48}As$ buffer was grown on (100) semi-insulating InP, followed by 800 Å of $In_{0.53}Ga_{0.47}As$. The composition was then digitally graded in 200 Å to InAs, followed by a relaxed 100 Å InAs layer and 75 Å of ErAs. The sample was then cooled to near room temperature and a 750 Å aluminum layer was grown to protect the ErAs from oxidation. Figure 1 plots the band diagram near the sample surface, illustrating the advantage of this structure for emitter Ohmic contacts. Figure 2 plots the measured resistance with pad spacing, yielding a contact resistivity of 8.5 Ω-μm^2. This proof-of-principle result is competitive, if not superior, to state-of-the-art emitter contact resistances that are typically ~5-10 Ω-μm^2. Morphological and contact resistance improvements from growth and structure modifications will be discussed.

If successful, these improved Ohmic contacts enable terahertz HBTs, opening up a myriad of terahertz circuit possibilities including tunable oscillators and receivers. Such advances can bridge the terahertz gap and enable low-cost and mass producible terahertz sensors and imagers.

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[1] M. J. W. Rodwell *et al.*, Trans. Electron Dev. **48**, 2606 (2001).
[2] C. J. Palmstrøm, in *Contacts to Semiconductors: Fundamentals and Technology*, ed. L. J. Brillson (1993).
[3] D. O. Klenov *et al.*, Appl. Phys. Lett. **86**, 241901 (2005).
[4] J. D. Zimmerman *et al.*, J. Vac. Sci. Technol. B **23**, 1929 (2005).

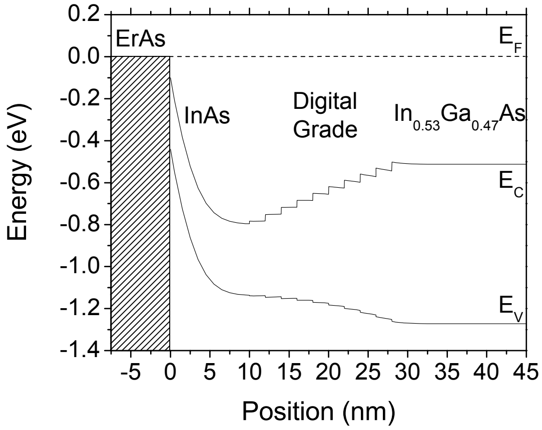

Fig. 1. Calculated band diagram of the ErAs/In(Ga)As Ohmic contact structure.

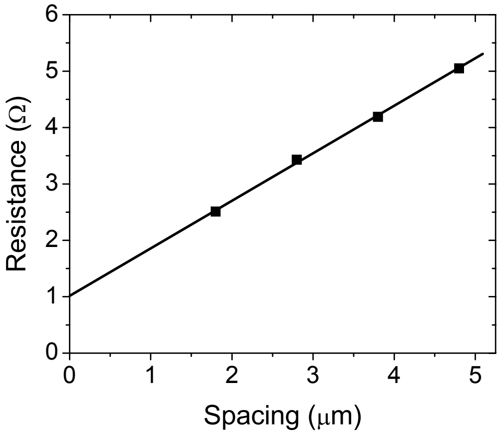

Fig. 2. TLM measurements of resistance versus pad spacing indicating a contact resistance of 8.5 Ω-μm^2.