Improved conductivity of GaAs-based tunnel junctions containing ErAs nanostructures via compositional grading

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Low-loss tunnel junctions are essential components of a number of optoelectronic devices and are particularly important for serially connecting the junctions of multijunction solar cells and minimizing electrical/optical losses in vertical-cavity surface-emitting lasers. The tunneling barrier in band-to-band tunnel junctions depends on the bandgap of the materials and the depletion layer thickness. Decreasing the bandgap reduces the tunneling barrier, enhancing the conductivity; however, the resulting increase in optical absorption can degrade device performance. On the other hand, reducing the tunneling distance by increasing the doping concentration shortens the depletion region and improves the conductivity; however, this approach is limited by dopant activation. Placing semimetallic ErAs nanoparticles at the pn junction greatly enhances tunneling currents by breaking the band-to-band tunneling process into two smaller back-to-back Schottky tunneling barriers [1, 2]. Modifying the ErAs nanoparticle size and density provides a route to further enhance conductivity [3]. Additionally, the Schottky barrier height between ErAs and III-V's has been found to be tunable by varying the III-V composition, which provides the motivation for this work [4]. Here, we investigate the combined benefits of compositional grading of the n-side Schottky barrier and ErAs nanoparticle-enhancement to produce an optimized Schottky barrier configuration (Figs. 1f and 1g), while only modestly increasing undesirable optical absorption.

Samples were grown in a Varian Gen II molecular beam epitaxy (MBE) system on n-type GaAs (100) substrates, under identical conditions to the best devices reported in Ref. [3]. Abrupt junctions with and without nanoparticles at the interface were grown and compared to graded junctions (Fig. 1). For the graded structures, GaAs was digitally graded to $In_{0.5}Ga_{0.5}As$ on the n-type side in five steps of 2 nm each. The p-side of the tunnel junction was not modified. It is important to note that although the InGaAs graded region has a smaller bandgap than GaAs, these layers are quite small as compared to the absorption depth of InGaAs and do not increase the loss significantly (~1% absorption for the case of surface normal absorption).

Through compositional grading, we observed an improvement in the conductivity, as compared to the abrupt ErAs junction (Fig. 2). The enhancement was as much as 7x in the forward bias, but was more modest under reverse bias. Experiments are currently underway to better understand the dichotomy between the performance under forward and reverse bias. This work is a proof-of-concept that tunnel junction conductivity can be further enhanced with band engineering. Future work could include the use of lattice-matched dilute-nitrides for grading the n-type side and mixed arsenide-antimonide-nitrides for the p-type side. These combined enhancements in ErAs tunnel junctions have the potential to further improve photonic device performance.

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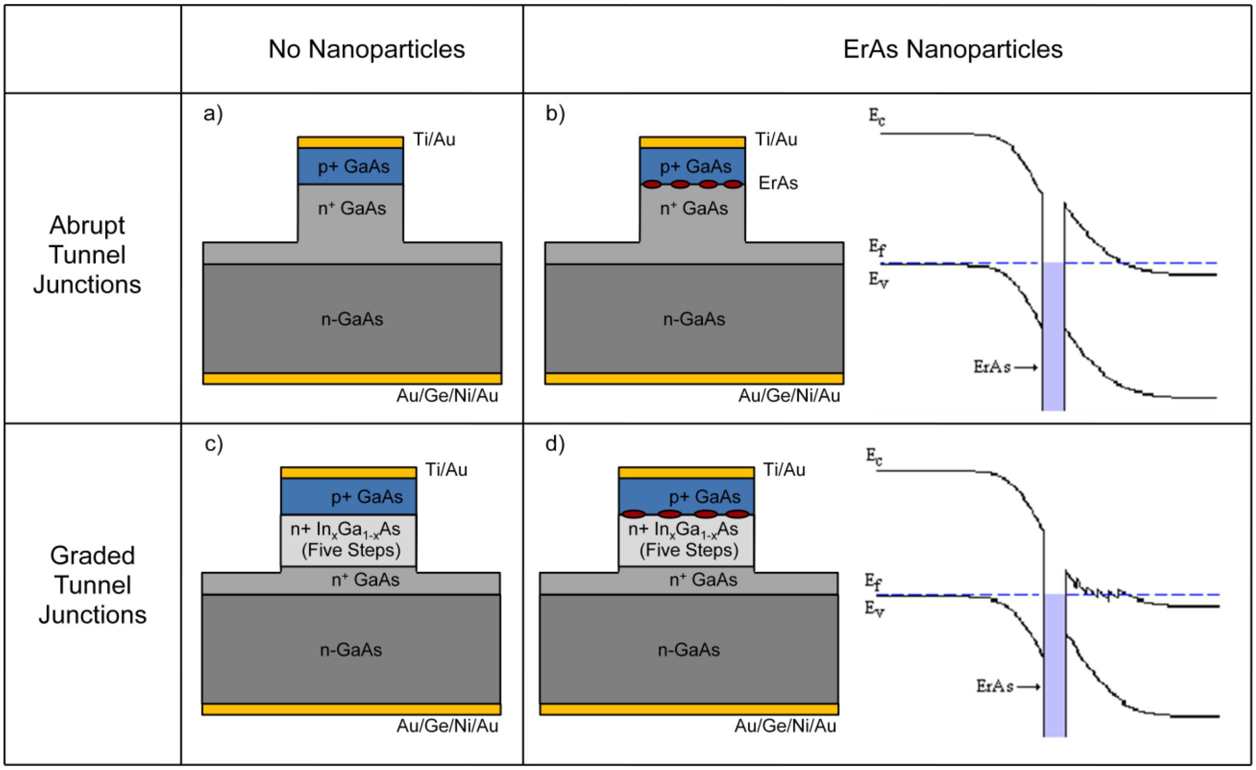

Figure 1. (a) Abrupt GaAs tunnel junction, (b) abrupt GaAs tunnel junction with ErAs nanoparticles and equilibrium band diagram, (c) $In_xGa_{1-x}As$ graded GaAs tunnel junction, and (d) $In_xGa_{1-x}As$ graded GaAs tunnel junction with ErAs nanoparticles and equilibrium band diagram.

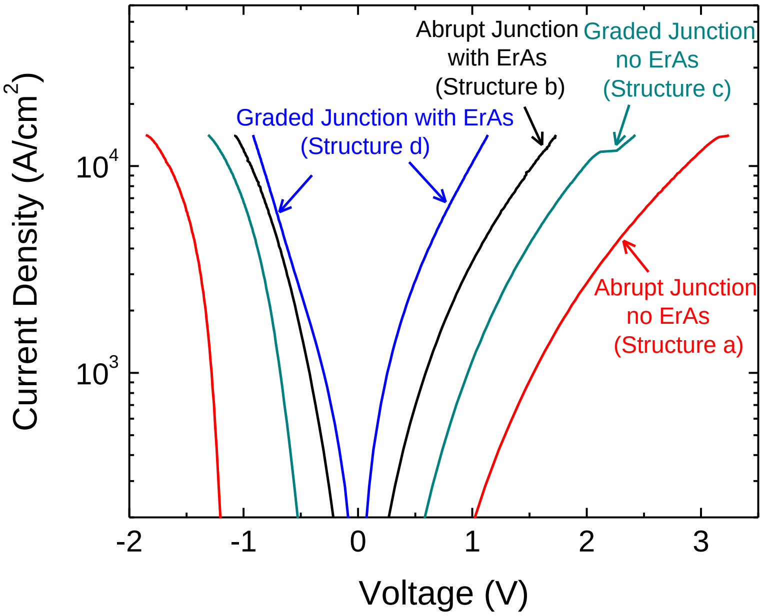

Figure 2. Current density versus applied voltage for the devices shown in Fig. 1.