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GaN_xAs_{1-x} Quantum Structures Fabricated by FIB Patterning

K. Alberi,*,** A.M. Minor,*** S.J. Chung,* D.E. Mars****, K.M. Yu**, W. Walukiewicz**, and O.D. Dubon*,**

* Department of Materials Science and Engineering, University of California, Berkeley, CA 94720
** Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
*** National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
**** Agilent Laboratories, Palo Alto, CA 94304

The GaN_xAs_{1-x} system belongs to a class of materials known as highly mismatched semiconductor alloys (HMA) in which a small amount of the anion is replaced by an isovalent impurity of a much different electronegativity. Anticrossing effects between the localized impurity states and the delocalized states of the matrix result in the lowering of the conduction band edge, as described by the band anticrossing model [1]. In the case of GaN_xAs_{1-x}, substitution of 1 mol % of N on the As sublattice results in a reduction of the bandgap by as much as 180 meV [2]. The ability to manipulate the bandgap by carefully controlling small concentrations of N makes this system well-suited for the formation of quantum wires and dots by alternative synthesis routes. Here we describe a technique to construct quantum structures from a $GaN_{0.015}As_{0.985}$ film using a focused ion beam.

An FEI Strata 235 dual-beam focused ion beam (FIB) operated at an accelerating voltage of 30 keV and a beam current of 1pA was used to selectively amorphize patterned lines by implanting Ga^+ ions. The ions were implanted at a 7° angle to the normal of a 10nm thick $GaN_{0.012}As_{0.988}$ film grown by molecular beam epitaxy on a semi-insulating GaAs substrate. Upon rapid thermal annealing (RTA), N is released from the As sublattice as these amorphous regions undergo solid-phase epitaxial regrowth, producing GaAs barriers surrounding the unimplanted $GaN_{0.012}As_{0.988}$ regions [3]. Depending on the implanted pattern, quantum wires or dots are generated.

Cross-sectional transmission electron microscopy (XTEM) analysis of the implant profile was carried out on FIB-patterned GaAs substrates and $GaN_{0.012}As_{0.988}$ films both before and after an RTA at 800 °C for 15s. The test structure consisted of 9 lines of implant doses ranging from 10^{13} to 10^{15} ions/cm^2, which were controlled by varying the ion beam scan times. The XTEM specimens were prepared in the FIB by a lift-out technique, and the surface of the sample was protected with a Pt layer deposited with the electron beam prior to ion milling. Figure 1 shows a montage of TEM micrographs from amorphized lines in a test structure used for preliminary investigation. The dark regions near the surface reveal the FIB-induced damage caused by the implantation of Ga ions. The spatial extent of amorphization depends on the implant dose, which is presumably due to the Gaussian distribution of the ion beam flux. XTEM of samples that were amorphized and then annealed show that even at the higher implant doses the amorphized lines recrystallized. Figure 2 shows two examples of an annealed sample, one with and one without residual defects.

Ion implantation using a FIB followed by RTA is demonstrated to be a viable method for amorphizing and regrowing selected regions of a film in such a way that quantum structures consisting of GaAs barriers surrounding regions of GaN_xAs_{1-x} can be constructed. Future studies will verify the electronic nature of the quantum structures through analytical TEM analysis.

References
1. W. Shan et al., *Phys. Rev. Lett*, **82**, 1221 (1999)
2. M. Kondow *et al., Jpn. J. Appl. Phys., Part 2* **33,** L1056 (1994).
3. K. Alberi, et al., *Proc. of ICPS-27, Flagstaff, AR, (2004)*
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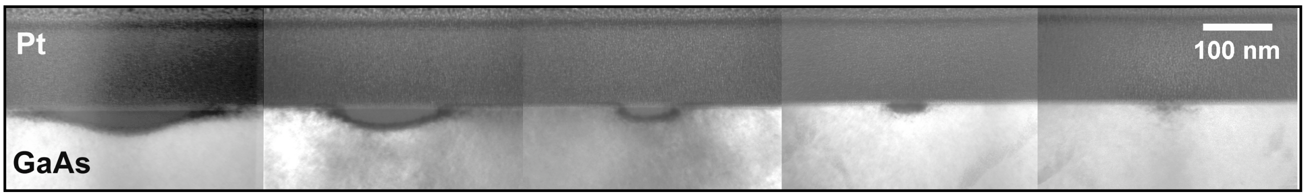

FIG. 1. Cross-sectional images of lines amorphized with varying Ga^+ implant doses. Implant doses ranged from 10^{15} ions/cm^2 (left) to 10^{13} ions/cm^2

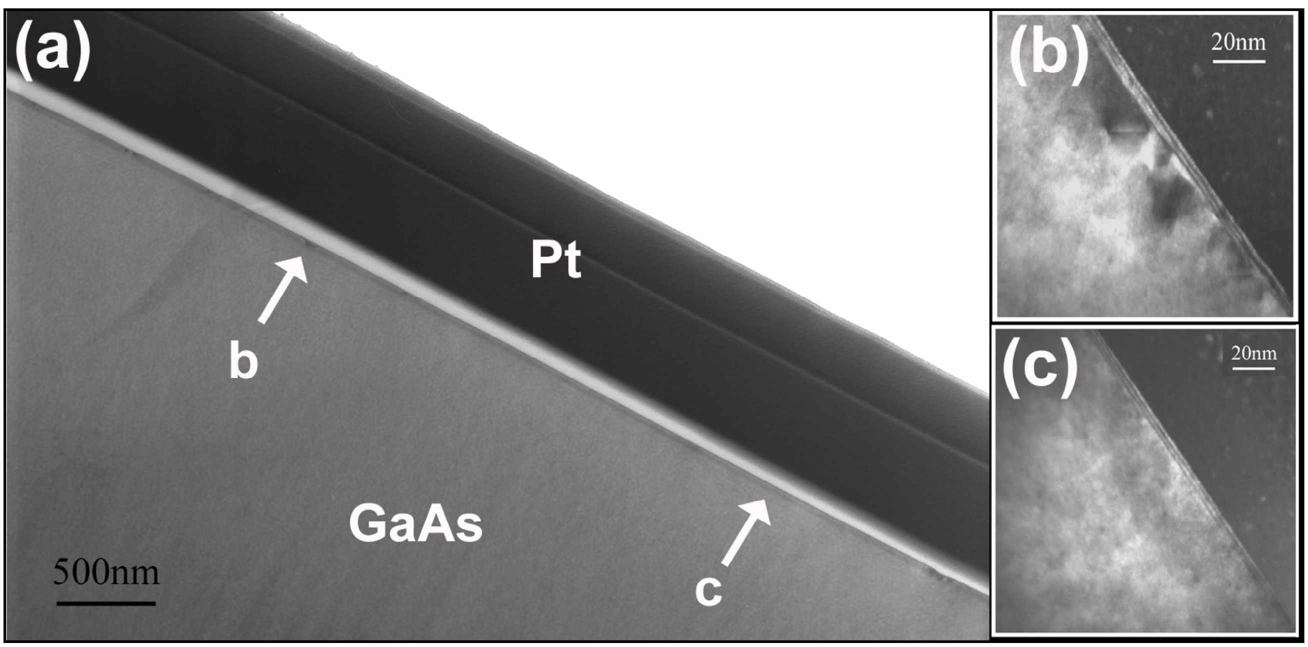

FIG. 2. Cross-sectional TEM images of an annealed test structure demonstrating recrystallization of the amorphized regions. (a) A BF cross-section of an annealed sample spanning multiple lines of which areas b and c are shown in figures (b) and (c). (b) F cross-sectional image showing residual defects in a line that had been implanted with $3x10^{14}$ ions/cm^2. (c) DF cross-sectional image showing a region that had been implanted with $3x10^{13}$ ions/cm^2 that shows no evidence of residual defects and complete crystal regrowth.

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