Optical characterization of AlN/GaN heterostructures

V. V. Ursaki, I. M. Tiginyanu,[a)] and V. V. Zalamai
Laboratory of Low-Dimensional Semiconductor Structures, Institute of Applied Physics, Technical University of Moldova, MD-2004 Chisinau, Moldova

S. M. Hubbard and D. Pavlidis
EECS Department, The University of Michigan, Ann Arbor, Michigan 48109-2122

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AlN/GaN/sapphire heterostructures with AlN gate film thickness of 3–35 nm are characterized using photoreflectivity (PR) and photoluminescence (PL) spectroscopy. Under a critical AlN film thickness, the luminescence from the GaN channel layer near the interface proves to be excitonic. No luminescence related to the recombination of the two-dimensional electron gas (2DEG) is observed, in spite of high 2DEG parameters indicated by Hall-effect measurements. The increase of the AlN gate film thickness beyond a critical value leads to a sharp decrease in exciton resonance in PR and PL spectra as well as to the emergence of a PL band in the 3.40–3.45 eV spectral range. These findings are explained taking into account the formation of defects in the GaN channel layer as a result of strain-induced AlN film cracking. A model of electronic transitions responsible for the emission band involved is proposed.
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INTRODUCTION

Electronic devices based on III–V nitride materials have recently shown great promise for high-frequency/high-power applications.[1–3] For the most part, these devices are based on low Al-composition, AlGaN/GaN heterostructure field-effect transistors (FETs). However, the gate barrier in the devices involved is based on Schottky contacts which have not yet proven to be stable at high temperatures. In contrast, metal–insulator–semiconductor (MIS)-based FETs can use high-temperature stable insulators at the interface. The use of an insulator at the gate can reduce gate leakage current in a device leading to improved low noise performance. In addition, a thin insulator, by placing the gate much closer to the two-dimensional electron gas (2DEG) channel, can help to improve the intrinsic transconductance of the device. AlN, with its relatively high dielectric constant (8.5) and wide band gap (6.2 eV), has the potential to be an excellent choice for the gate dielectric in GaN based MISFET devices.[4,5]

However, from the growth standpoint, it is difficult to grow high-quality AlGaN layers with high Al content. The problems of lattice mismatch (2.47% for AlN on GaN), prereactions between trimethylaluminum and ammonia, and three-dimentional growth must be overcome for effective high-quality AlN/GaN-based MISFET devices.[6,7] As a result, the number of reports on transport properties of $Al_XGa_{1-X}N$/GaN structures with $x>0.5$ is very limited.[4–7] Nevertheless, the recently achieved values of room-temperature electron mobility ($\sim$900 $cm^2/V\,s$) in AlN/GaN heterostructures[7] are very close to the typical values in AlGaN/GaN structures (1000–1600 $cm^2/V\,s$). At the same time, due to the much larger polarization induced electric fields in AlN/GaN structures, the 2DEG density in this case is several times higher compared to that in AlGaN/GaN heterostructures.[6,7]

While the role of the 2DEG channel in the transport properties of $Al_XGa_{1-X}N$/GaN heterostructures is well understood, the data related to the radiative recombination of 2DEG in these structures are scarce and contradictory.[8–11] This is in contrast with $Al_XGa_{1-X}As$/GaAs heterostructures where optical properties related to the recombination of the 2DEG are well documented.[12–14] The respective differences between $Al_XGa_{1-X}As$/GaAs and $Al_XGa_{1-X}N$/GaN heterostructures can be attributed to the very strong piezoelectric polarization in the AlGaN layer on GaN[15,16] that leads to rapid diffusion of photoexcited holes into the flatband region of GaN in $Al_XGa_{1-X}N$/GaN heterostructures. Therefore, the probability of recombination between the 2DEG and photoexcited holes is much lower in $Al_XGa_{1-X}N$/GaN heterostructures than in $Al_XGa_{1-X}As$/GaAs ones. The higher the Al content, the stronger the piezoelectric field, thus reducing the chance to observe radiative recombination of the 2DEG. On the other hand, the higher the Al content, the larger the lattice parameter and thermal expansion coefficient mismatches between AlGaN and GaN. Hence, the probability of defect formation at the $Al_XGa_{1-X}N$/GaN interface increases with Al content and, consequently, recombination mechanisms alternative to the 2DEG recombination are expected.

No data are reported to date on radiative recombination mechanisms at an AlN/GaN interface. The goal of this work is to make use of optical methods such as photoreflectivity (PR) and photoluminescence (PL) for the characterization of AlN/GaN interfaces in an attempt to shed light upon the radiative recombination channels in $Al_XGa_{1-X}N$/GaN heterostructures at high Al content.

[a)]Author to whom correspondence should be addressed; electronic mail: tiginyanu@mail.md

