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Low frequency noise in GaAs structures with embedded In(Ga)As quantum dots

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Abstract

Current–voltage and low frequency excess electrical noise characteristics of two different—Schottky diode and n-i-n diode—GaAs structures embedded with self-assembled In(Ga)As quantum dots are reported. We find the growth of quantum dots induces defects not only near the quantum dot but also extended to quite a distance toward the growth direction. In Schottky diode structure, comparing with the reference sample without the quantum dot layer, the current dependence of the low frequency noise spectral density indicated that the noise is from the generated interface states with the density increasing towards the band tail. Also the crystal quality of the Schottky diode including the quantum dot layer, deduced from the Hooge parameter, was slightly worse than that of the reference sample. For n-i-n diode structure, the current–voltage relation was linear, and a quadratic current dependence of the noise spectral density was observed. The Hooge parameter for the n-i-n structure was determined to be on the order of unity indicating the general degradation of the structure.

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1. Introduction

Self-assembled quantum dots (QD's) provide unique opportunity for new physics and device applications due to their quasi-zero-dimensional nature [1–3]. There have been extensive studies utilizing different technique including capacitance measurements, deep level transient spectroscopy, and conductance measurements in conjunction with optical methods such as photoluminescence measurements [4–7]. Since a lot of stress is involved during the growth of the QD's, lattice defects are likely generated and diffused during the growth of the structure involving QD's. Indeed, many works have been reported on the QD stress engineering including insertion of strain-relief layer for better device performance [8] and addition of high barrier layer to control the energy levels of the QD [9].

Low frequency excess electrical noise or $1/f$ noise in semiconductor structures is known to provide a diagnostic tool for defect related properties of the materials and the structure. It also limits the device performance in many cases. However, not many reports on the low

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frequency noise studies on QD's are found in the literature. Hastas et al. [10,11] have reported the results of noise characteristics in GaAs Schottky diode embedded with InAs QD's similar to the structure in this study. However they obtained abnormally large density of interface states, which they attributed to the barrier height inhomogeneity. We have reported preliminary results of low frequency noise study on structures including QD layers [12], which were quite different from those of Hastas et al.'s. In this work, we further discuss the results of the analysis on the current–voltage and low frequency noise characteristics in Schottky diodes and n-i-n diodes with embedded QD layers.

2. Epitaxial growth

In this work, atomic layer molecular beam epitaxy (ALMBE) technique was employed to grow epitaxial layers and QD's. ALMBE is known give more control of size distribution of QD's and no wetting layer [13]. For Schottky diode structures, samples were grown on (001) silicon doped n^+-GaAs substrates. After thermal removal of surface oxides at the substrate temperature of 600 °C, 1 μm-thick n-typed GaAs buffer (doped with silicon) was grown at 580 °C, then a single InAs QD layer was sandwiched by 100 Å-thick GaAs layers and capped by a 0.4 μm-thick n-typed GaAs layer, at 480 °C. For a reference sample, the same structure without QD layer was prepared. Total coverage of InAs was 3 MLs. Growth rate of InAs and GaAs were ~0.07 ML/s and ~0.5 ML/s, respectively. Average width, height and density of the InAs QDs were ~40 nm, ~7 nm, and $4.1 \times 10^{10}/cm^2$, respectively. After epitaxial growth, Au contacts were fabricated by thermal evaporation through metal mask with 0.3 mm diameter holes.

For n-i-n diodes, the samples were grown on (001) semi-insulating GaAs substrate. After deoxidization of surface oxide, approximately a 700 Å-thick GaAs buffer, a 500 Å-thick $Al_{0.3}Ga_{0.7}As$, 20 pairs of a 20 Å-thick $Al_{0.3}Ga_{0.7}As$ and a 20 Å-thick GaAs short period superlattices, and a 0.7 μm-thick n-type doped GaAs layer ($2 \times 10^{18}/cm^2$) were deposited at 570 °C, sequentially. Three stackings of InGaAs QD layer were grown separated by 250 Å-thick GaAs layer. On top of the structure, a 400 Å-thick $Al_{0.3}Ga_{0.7}As$ and a 0.2 μm-thick n-type doped GaAs layer ($2 \times 10^{18}/cm^3$) were deposited. Growth rates of InAs and GaAs are 0.07 ML/s and 1 ML/s respectively. Average width, height and density of the InGaAs QDs are ~50 nm, ~7 nm, ~$1 \times 10^{10}/cm^2$, respectively. The final diode structure was fabricated by using standard procedures: photolithography, wet chemical etching, metal deposition and lift-off, and rapid thermal annealing for ohmic contact. Photolithography and wet chemical etching were used to define the device mesas, which had an area of 5 mm^2. Thermal evaporation of AuGe/Ni/Au and lift-off process were performed to form the top and bottom contacts with an area of 0.25 mm^2. A rapid thermal annealing was followed at 400 °C for 30 s in nitrogen ambient.

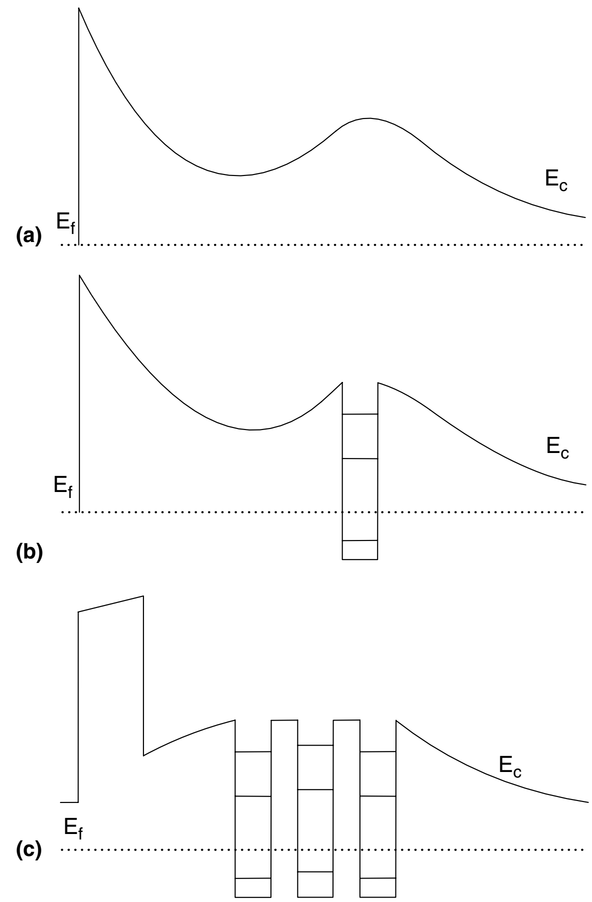

Fig. 1. Schematic diagram of the conduction band, for (a) the reference Schottky diode, (b) the Schottky diode with a QD layer, and (c) the n-i-n diode with three QD layers and an AlGaAs current blocking layer.

The conduction band diagram is schematically depicted in Fig. 1, for the reference Schottky diode (a), the Schottky diode with embedded quantum dot layer (b), and the n-i-n diode with three QD layers in the intrinsic region (c).

3. Measurements, results and discussion

Fig. 2 shows the current–voltage characteristics of three different structures at room temperature. For Schottky diodes, thermionic emission is known to be the main conduction mechanism and the current–voltage relation can be expressed in terms of the saturation current, ideality factor, series resistance and parallel leakage resistance. However we find the series resistance is bias dependent and the simple extraction method [14] could not be applied. From the linear part of dV/dln$I$,