Electroluminescence from a GaAs/AlGaAs Heterostructure at High Electric Fields: Evidence for Real- & *k*-Space Transfer

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Abstract: We study impact-ionization-induced electroluminescence (EL) from a GaAs/AlGaAs heterostructure under high bias. In addition to *k*-space transfer (the Gunn effect), EL spectra indicate real-space (GaAs-to-AlGaAs) transfer. Microscopy shows strong EL near the anode.
OCIS codes: (300.6280) Spectroscopy, fluorescence and luminescence; (160.2540) Fluorescent and luminescent materials

1. Introduction

Planar Gunn diodes have been proposed as a small, cheap, high-power output, low-power consumption, and room-temperature-operating terahertz (THz) source [1]. When biased at high DC voltage, negative differential resistance (NDR) occurs due to *k*-space hot-electron transfer from the Γ valley to a side valley (known as the Gunn effect), which leads to the formation of high-field domains. Impact ionization then ensues, which produces an avalanche of electron-hole pairs in a cascading fashion, resulting in band-edge electroluminescence (EL) via subsequent recombination of electrons and holes [2].

Here, we report on EL spectroscopy study of a planar Gunn diode. We observe strong EL, whose intensity increases superlinearly with increasing DC bias. In addition to EL from the GaAs band-edge, we identify a new EL feature coming from the band-edge of AlGaAs, which suggests that GaAs-to-AlGaAs real-space charge transfer occurs at the same time as *k*-space inter-valley transfer. Furthermore, we investigate the spatial distribution of EL in a long-channel device, and show a clear concentration of EL near the anode, consistent with the notion that the high-field domain grows as it propagates from the cathode towards the anode.

2. Device structure

Figure 1(a) shows a cross section of the GaAs/AlGaAs heterostructure studied, which was grown by molecular beam epitaxy on a semi-insulating GaAs substrate. The structure was modulation doped with Si (at a density of ~6.8 $\times 10^{17}$ cm^{-3}) in the middle of the $Al_{0.339}Ga_{0.661}As$ layer. A two-dimensional electron gas (2DEG) was formed on the GaAs side of the interface between the bottom 20-nm $Al_{0.339}Ga_{0.661}As$ layer and the GaAs buffer layer underneath. Alloyed Ohmic contacts were made by depositing a Ni(8 nm)/Ge(24 nm)/Au(54 nm)/Ni(14 nm)/Au(100 nm) composite on the GaAs cap layer and then annealing at 480 °C. The channel length of the device was ~ 360 μm.

3. Results and discussion

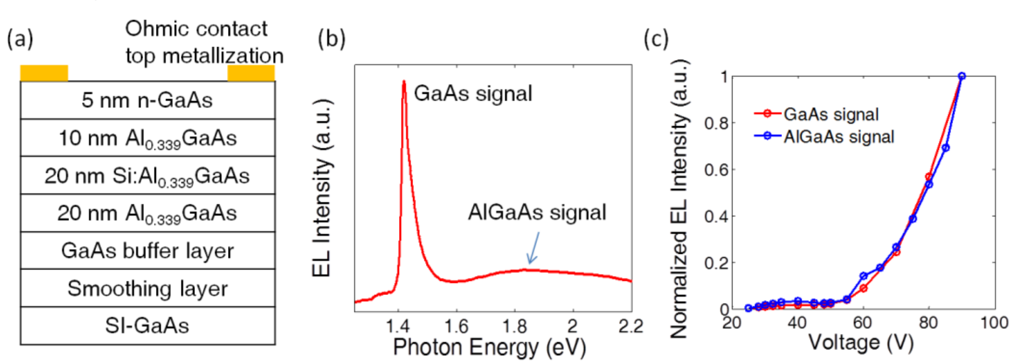

Figure 1: (a) Vertical structure of the GaAs/$Al_{0.339}Ga_{1-0.339}As$ heterostructure studied. (b) Representative EL spectrum indicating two significant peaks when the bias is higher than a threshold. (c) A plot of normalized integrated EL intensity from GaAs and AlGaAs as a function of voltage applied between the anode and cathode contacts, indicating the close correlation of these two signals which share the same threshold ~55 V.

EL spectra were collected with a multimode optical fiber and analyzed at room temperature with a grating spectrometer equipped with a liquid nitrogen cooled charge-coupled-device (CCD) camera. Figure 1(b) shows a representative EL spectrum when the bias is 90 V, corresponding to the NDR regime. A sharp peak is seen from the bulk GaAs layer, with a peak photon energy of 1.424 eV, along with a broad peak from the $Al_{0.339}Ga_{0.661}As$ layer at ~1.85 eV. The latter peak indicates real-space transfer of hot electrons and holes from the 2DEG to the AlGaAs layer. The spectrally-integrated EL intensity is plotted as a function of DC voltage between the cathode and anode in Fig. 1(c); the intensity is normalized by the value at the highest DC voltage (90 V). It can be seen that the signals are strongly correlated to each other, emerging at the same threshold voltage and increasing at the same rate.

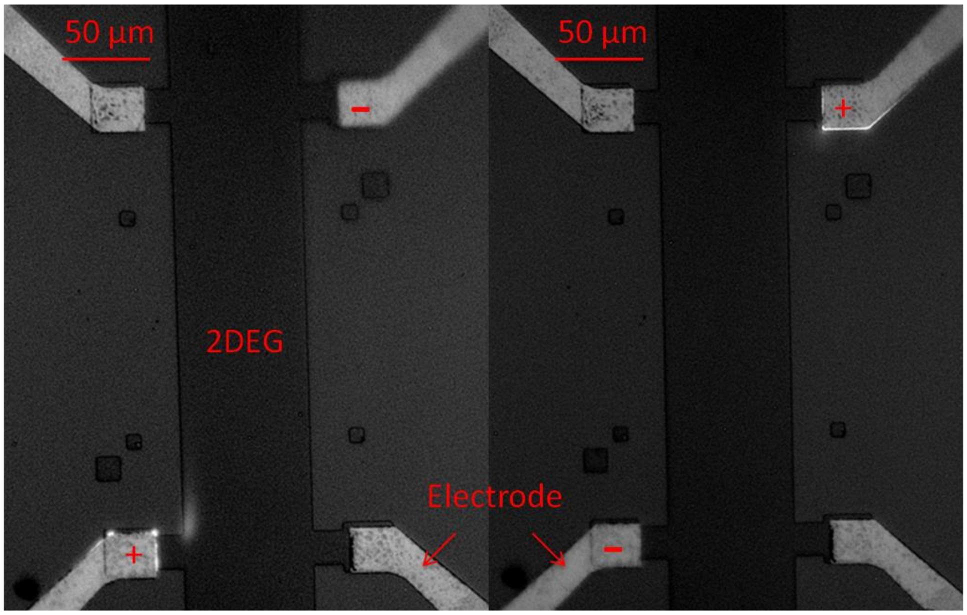

Figure 2: Microscope image of EL spatial distribution under different current polarity. The positive (negative) sign denotes the anode (cathode). The dark Hall bar contains the 2DEG while other regions are completely etched. The four bright areas are the Ohmic electrodes.

The spatial distribution of EL in our device was also investigated by collecting the emitted light with a 10× objective lens in a commercial optical microscope, equipped with a sensitive black-and-white CCD camera with controlled exposure times. The EL mapping is shown in Fig. 2, revealing asymmetric EL patterns along the channel. The EL intensity is largest near the anode regardless of current direction, indicating that the electric field is maximal near this contact. This can be explained as a combination of the low hole mobility and the propagation and growth of the high-field domain towards the anode [3]. Furthermore, our mapping confirms that the EL signal occurs only within the lateral regions that contain the 2DEG, which suggests that the impact ionization process is initiated by hot electrons in the 2DEG.

[1] A. Khalid *et al*., “A Planar Gunn Diode Operating Above 100 GHz,” IEEE Electron. Dev. **28**, 849-851 (2007).

[2] H. P. Zappe *et al*., “Electroluminescence from Gunn domains in GaAs/AlGaAs heterostructure field effect transistors,” J. Appl. Phys. **68** 2501-2503 (1990).

[3] M. Montes Bajo *et al*., “Impact ionisation electroluminescence in planar GaAs-based heterostructure Gunn diode: Spatial distribution and impact of doping non-uniformity,” J. Appl. Phys. **113**, 124505 (2013).