Electroluminescence and gate current components of InAlAs/InGaAs HFET's

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Increasing the InAs mole fraction in InGaAs-base heterostructure FET's (HFET's) leads to improved device performance due to the superior carrier transport properties of these materials. At the same time, however, the use of narrow band-gap semiconductors results in enhanced impact-ionization, with severe detrimental effects like excessive shot noise in I_D and large gate current I_G even at regular bias points.

Detailed physical understanding of impact-ionization and of the behaviour of the copious amount of holes that are generated in InGaAs channels is crucial to developing guidelines for designing high-performance devices. Gate current measurements and electroluminescence spectra have been widely adopted to evaluate hot-electron effects and impact-ionization in GaAs-based MESFET's and HEMT's, but no agreement has been found as of the origin of the different spectral components of the emitted radiation. In any case, no work has been presented, up to now, in InGaAs-based HFET's. In this paper we carry out a detailed study of gate current and its correlation with the various spectral components of light emitted in InAlAs/InGaAs HFET's at regular bias points.

Our work reveals that light emitted in the visible portion of the spectrum is a good signature of impact-ionization in the channel as impact-ionized holes recombine with channel electrons. On the other hand, light emitted in the infrared portion of the spectrum is found to originate in conduction band-to-conduction band transitions of the hot electrons in the channel. These findings establish electroluminescence in the appropriate spectral range as an ideal tool to characterize hot carrier phenomena in InP-based HFET's, and allowed us for the first time to *quantitavely* separate the gate current into its electron and hole components.

The devices characterized in this work are n-channel normally-on L_g = 1 μm InAlAs/InGaAs HFET's, with an 100 Å n^+ - $In_{0.53}Ga_{0.47}As$ Si-doped channel (N_{Si} = 6 x 10^{18} cm^{-3}), a 300 Å $In_{0.41}Al_{0.59}As$ strained insulator and a 50 Å $In_{0.53}Ga_{0.47}As$ cap layer. When these devices are biased at high V_{ds} (≥3 V), significant impact-ionization takes place in the channel. A detailed study of the gate current reveals that, for negative V_{gs}, I_G is dominated by collection of impact-ionized holes, while for positive V_{gs}, I_G is dominated by electron real-space-transfer at low V_{ds}, and by hole collection at high V_{ds}.

Light emission both in the infrared and visible region takes place at high V_{ds}. The intensity of the emitted light increases remarkably by increasing V_{ds} or by decreasing T. For energies higher than 1.5 eV all spectra exhibit nearly Maxwellian distributions, with effective temperatures T_{eff} in the 1170 K - 1360 K range. T_{eff} increases with increasing V_{ds} and decreasing T. The intensity of the integrated light in the 1.1 eV - 1.25 eV range is found to be proportional to I_D, thus suggesting conduction band-to-conduction band transitions as the dominant light emission mechanism in the infrared range. This mechanism, although predicted by simulations on GaAs MESFET's, has never been demonstrated experimentally. In the 2.0 eV - 2.5 eV range, the integrated light emitted correlates well with the $I_G \times I_D$ product, suggesting conduction-to-valence band recombination as the emission mechanism. At high V_{gs} and high temperatures, the quality of the correlation degrades, revealing the increasing relevance of electron real-space-transfer in I_G. This fact allows us to separate for the first time the electron (I_{Ge}) and hole (I_{Gh}) contributions of the gate current.

In conclusions, the emission mechanisms of light induced by hot electrons in InGaAs/InAlAs HFET's have been identified and electroluminescence intensity has been correlated with electrical characteristics; these measurements can now be used by device designers to quantitatively evaluate impact-ionization phenomena and real-space-transfer effects in these devices and, by applying the same methodology, in other FET structures.

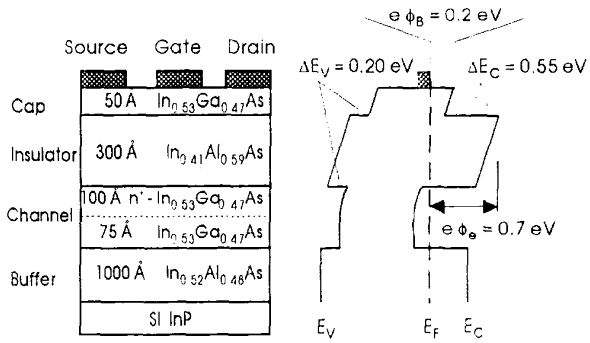

Fig. 1: Schematic cross section and band structure

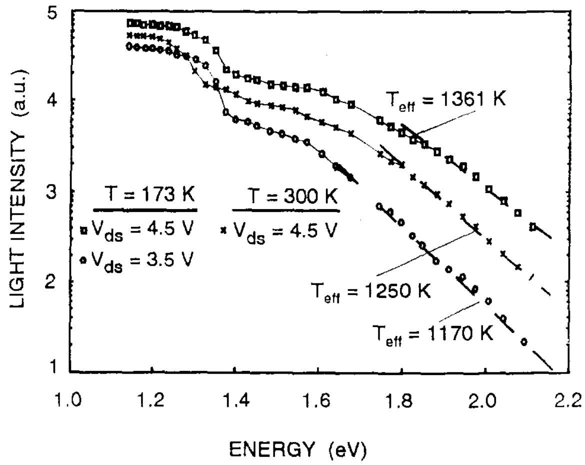

Fig. 4: Light emitted spectra for different V_{ds} and different T

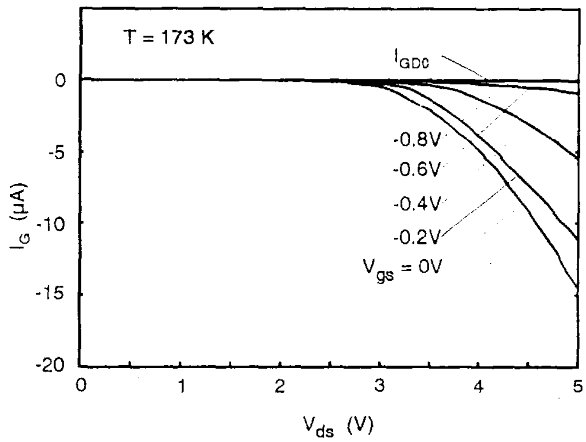

Fig. 2: I_G vs V_{ds} for negative V_{gs}. I_G is dominated by collection of holes; I_{GDO} is the reverse current of G-D diode with source floating.

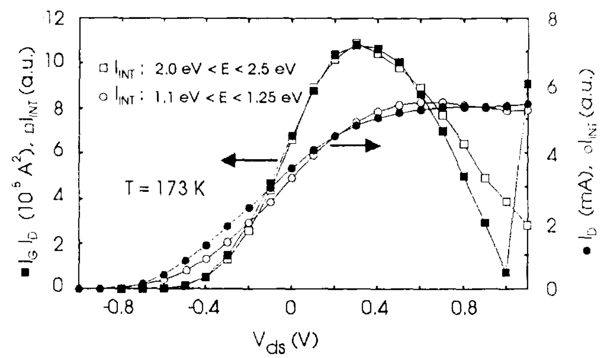

Fig. 5: Correlation between light intensity and I_D (infrared region) and I_G x I_D (visible region). The discrepancy observed in visible region for V_{gs} > 0.6 V is due to contribution of RST of elctrons to I_G.

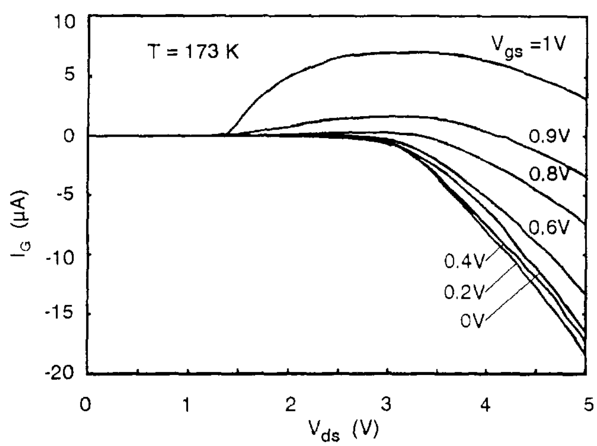

Fig. 3: I_G vs V_{ds} for positive V_{gs}. I_G is dominated by RST of electrons at low V_{ds}, but it contains

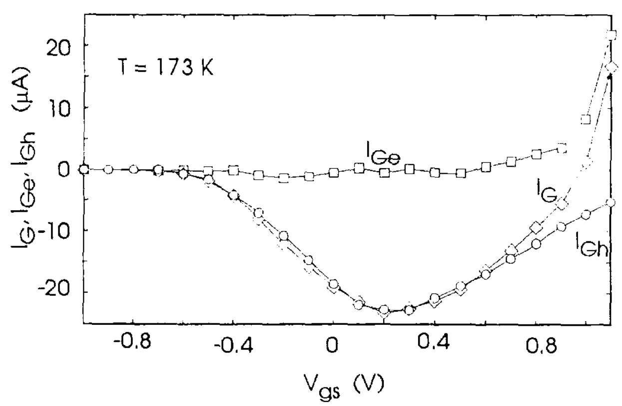

Fig. 6: I_G, I_{Gh}, I_{Ge} as a function of V_{gs}. I_{Gh} is the component of I_G due to collection of holes. I_{Ge} is the component due to RST of electrons, which induces the breaking of the correlation between I_{INT} and I_G x I_D for V_{GS} > 0.6V, Fig. 5.