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Light Emission From Travelling Space Charge Domains

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Abstract

We report light emission from n-doped GaAs epilayers associated with impact ionization when the device is biased in the negative difference resistance (NDR) regime (F>3.5 kV cm^{-1}). Spectral distribution of the emitted light (electroluminescence) has been measured to identify the energy distribution of the recombining electron-hole pairs. Electron temperatures, calculated from the high energy tail of the electroluminescence spectra, show that the light emission is due to the recombination of the impact ionized holes with the background, channel, and the travelling space charge electrons. The range of the electron temperatures obtained indicate that the contribution to the light emission from the high field domain electrons increases with reducing sample lengths.

Introduction

The study of hot electron effects has become increasingly important in electronic devices as dimensions shrink. One such effect is the light emission phenomena associated with impact ionisation [1]. Hot carrier light emission from devices based on III-V and II-VI material systems, biased in the Negative Differential Resistance (NDR) region, has been observed since the mid-sixties. Early devices investigated were of dimensions in the mm range [2]. With the advent of sophisticated crystal growing techniques like MBE, MOVPE, and lithographic techniques like ion beam etching and plasma etching, it has now become possible to design devices with spatial dimensions reduced to the sub-micron scale. There are two reasons for the increased interest in the studies of hot electron light emission in such devices. Firstly, the study of hot-electron light emission can give information about underlying physical phenomena such as impact ionisation that occurs in heavily doped materials with a high density of conduction electrons. Secondly, from an engineering point of view, in micron and submicron devices operated at bias voltages close to or above the NDR threshold, degradation of performance characteristics or breakdown can occur [3]. It is therefore, desirable to understand the phenomena for improved device reliability.

Some of the most recent work has investigated GaAs based devices such as Metal Semiconductor Field Effect Transistors (MESFETs) [2,3], High Electron Mobility Transistors (HEMTS) [3,5], PsedoMorphic HEMTs (PM-HEMTs) [2,5], Heterostructure Bipolar Transistors (HBTs) [3,7] and similar devices based on other material structures [3]. The devices studied have channel lengths usually between 0.5 and 5μm. Most studies involve the DC biasing of the devices at electric fields above NDR threshold and the measurement of spatially and temporally averaged luminescence. The most striking difference between the earlier work [2] and the current reports [3-7] is the wide diversity in the electron temperatures as measured from the light emission spectra. Electron temperatures, determined from the high energy tail of spectra by assuming a Maxwellian distribution, are currently reported to vary in the range between a few 1000K [3] to about 15000K [8]. These temperatures are much higher than those reported in mm-size bulk GaAs ($\sim$300K at T_L=300K) [2]. The reason for such diversity has yet to be explained. Another fundamental problem associated with the hot electron light emission, is the actual mechanism responsible for the carrier generation and recombination phenomena. In order to explain the observed light emission a number of mechanisms have been suggested. These include inter-band recombination of the impact ionised electron hole pairs, Bremsstrahlung, electron impurity transitions, and inter-conduction band transitions [3-8]. All the models assume a thermalized distribution of very hot electrons, however, there is no conclusive evidence to support fully any of the proposed mechanisms.

The aim of this work is to address these problems by bridging the gap between the earlier work on mm size devices and the current work on μm size devices through the investigation of the phenomena in devices with lengths between a few to a few hundreds of micrometers.

Experiment Results and Discussion

Samples investigated in this study were grown by MBE. The structure consists of a 2μm thick n-GaAs layer with the doping (Si) concentration of 1×10^{17}cm$^{-3,}$ grown on semi-insulating GaAs. The samples used in this study were fabricated in the form of simple bars and ohmic contacts were formed by alloying Au/Ge/Ni. Electric field pulses of duration between 5 and 100 ns were applied with a duty cycle of less than 10^{-4} to minimize the Joule heating. The spectral and integrated electroluminescence measurements were carried out by employing orthodox gating techniques as described by us elsewhere [9]. The length of samples used in the experiments were varied between 5 and 150 μm. In the experiments the image of the whole sample was focused onto monochromator slits. The electroluminescence (EL) was, therefore, representative of emission from the whole surface.

Figure 1a shows the current density-field characteristic of a 150μm long sample at a lattice temperature of 300K. Bifurcations in the figure indicate the electric fields at and above which the current instabilities and light emission occur. It is evident from the figure that NDR in the samples occur at high enough fields for intervalley transfer of hot electrons. The EL spectrum of the same sample shown in Figure 1b is measured at an applied electric field of F=3.625kV/cm. The EL spectrum has a single emission peak at $h\nu$=$1.43eV$ corresponding to band-to-band transition [10]. The spectrum has a prominent high energy tail indicative of a distribution of carriers at non-equilibrium temperatures. Electron temperatures can be calculated from the high energy tail of the EL spectrum by plotting the logarithm of the EL spectrum by plotting the logarithm of the EL intensity versus photon energy as shown in Figure 2. At a given electric field (F) the linear dependence of the log EL intensity as a function of photon energy can be described by a Maxwell-Boltzmann distribution characterized by a carrier temperature $T_e > T_L$ [11]:

$$I_{EL} \propto exp(-\hbar w/k_B T_e),$$

where $I_{EL}, \hbar w, k_B$ and T_E are the EL intensity, emitted photon energy, Boltzmann constant and electron temperature, respectively. The slope of the linear regions therefore can be used to extract the electron temperature.

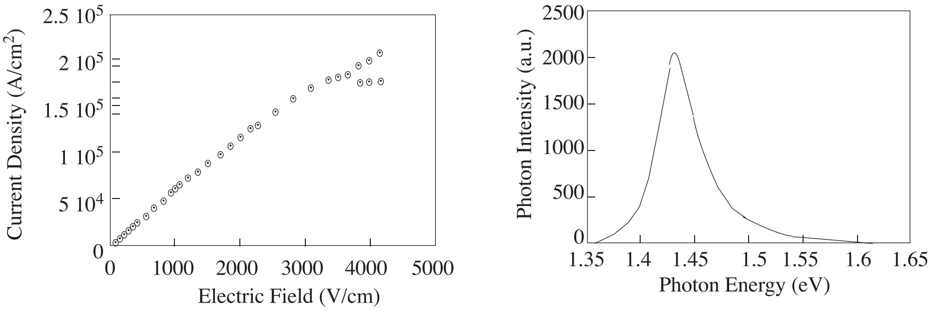

Figure 1. (a) Current density-Field characteristic of a 150μm sample at T_L=300K. The bifurcations indicate the electric fields above which instabilities and light emission occur. (b) EL spectrum from the same sample measured at electric field F=3.625kV/cm.

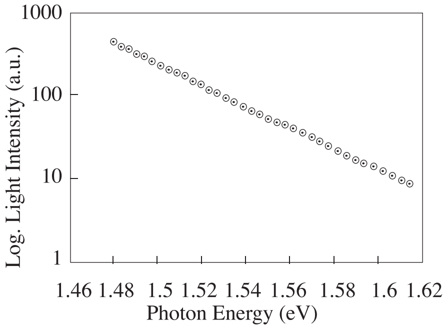

Figure 2. Logarithm of the high energy tail of EL spectrum at T_L=300K. Electron temperature is T=300K in a sample length of 150μm.

The electron temperature for Figure 2 is T_e=390K, which is significantly higher than its lattice temperature. The recombination of emission is due to both he equilibrium electrons in the channel and the hot electrons in the high field domain with non-equilibrium holes created within the domain via impact ionisation as suggested by Balkan *et al.* [12]. Because the EL is measured from the whole sample. Similar measurements were carried out for a range of sample length vary between 5-150μm and the electron temperatures were recorded at F>F_{th} (where F_{th} is threshold electric for NDR). These results are shown in Figure 3. Also shown in the figure are the results obtained by Southgate [2] on mm size sample and by Zanoni *et al.* on a few μm size functional devices such as MESFET and HEMT structures [13].

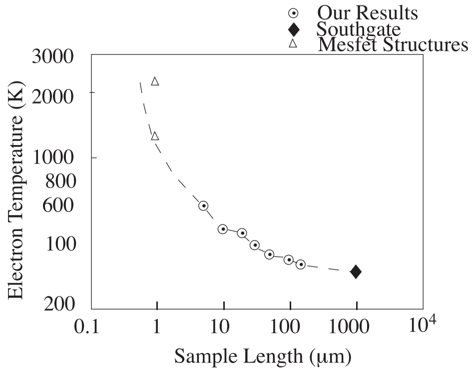

Figure 3. Electron temperatures as a function of sample length for n-GaAs in the NDR regime at T_L=300K including with mm and μm lenght devices. The broken line is guide the eye.

As it is seen from Figure 3, electron temperatures increase with reducing sample lengths. This is explained by when the sample lengths reduce, the contribution to the recombination of emission from hot electrons in high field domains with non-equilibrium holes created within domain via impact ionization increases. This will cause the increase in electron temperature.

Summary and Conclusion

We have reported the first studies of device length dependence of electron temperature in GaAs structure biased in the NDR. Observed light emission is due to the recombination of high field domain electrons and equilibrium electrons with non-equilibrium holes. When the device lengths are reduced, the ratio of the recombination of domain electrons with impact ionised non-equilibrium holes increases. This leads to increase in electron temperature.

References

[1] C. Canali, C. Tedesco, E. Zanoni, M. Manfredi, A. Paccagnella, in "*NDR and Instabilities in 2-D Semiconductors*", edited by N. Balkan, A. J. Vickers and B. K. Ridley, Plenum Press, New York (1993).

[2] P. D. Soutgate, *J. Appl. Phys.,* **18,** (1967)

[3] C. Canali, C. Tedesco, E. Zanoni, M. Manfredi, A. Paccagnella, "*NDR and Instabilities in 2D Semiconductors*" p:215, edited by N. Balkan, B. K. Ridley and A. J. Vickers, Plenum Publ. New York (1993).

[4] A. Paccagnella, E. Zanoni, C. Tedesco, C. Lanzieri, A. Cetronio, *IEEE Electr. Dev.*., **38,** 2682 (1991)

[5] H. P. Zappe, D. J. As, *Appl. Phys. Lett.,* **59,** 2257 (1991)

[6] F. Aniel, P. Boucaud, A. Sylvestre, P. Crozat, F. H. Julien, R. Adde, *J. Appl. Phys.,* **77**, 2183 (1995)

[7] E. Zanoni, L. Vendrame, P. Pavan, M. Manfredi, S. Bigliardi, R. MAlik, *Appl. Phys. Lett.,* **62,** 402 (1993)

[8] R. Ostermeir, F. Koch, H. Brugger, P. Narozny, H. Dambkes, *Semicond. Sci. Technol.,* **9**, 659 (1994)

[9] R. Gupta, N. Balkan, B. K. Didley, *Phys. Rew.,* 46: 7745 (1992)

[10] S. Sze, "*Physics of Semiconductor Devices*", 2nd., Wiley, New York (1981)

[11] N. Balkan, B. K. Ridley, M. Emeny and I. Goodgridge, *Semicond. Sci. and Technol.,* 4, 1142 (1989)

[12] N. Balkan, M. Hostut, T. de Kort and A. Straw, "*Hot Carriers in Semiconductors*" edited by K. Hess *et al.*, Plenum Press, New York, 1996.

[13] C. Canali, C. Tedesco, E. Zanoni, M. Manfredi, and A. Paccagnella, p 215 in "*NDR and Instabilities in-2-D Semiconductors*" edited by N. Balkan, A. J. Vickers and B. K. Ridley, Plenum Press, New York (1993)