COOLING OF HOT CARRIERS IN INTERMIXED GaAs/AlGaAs QUANTUM WIRES AND DOTS

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INTRODUCTION

In optoelectronic applications low dimensional structures are discussed as promising for devices with fast modulation response. Up to now the realized quantum wire and quantum dot lasers yield no improvement in modulation response. A possible reason that no improvement could be observed may be the changed carrier scattering and capture mechanisms in quasi 1D and 0D systems. Theoretical calculations predict bottleneck effects¹ which can be proved in low dimensional semiconductor systems with systematically varied sizes. The interest in these studies is twofold i) investigation of carrier scattering from regions of high to low dimensionality and ii) investigation of carrier phonon interaction in quasi 1D and 0D structures. We are able to distinguish these different processes on the one hand by variation of the laser excitation wavelength and on the other hand by the realization of quantum wires (QWWs) and quantum dots (QWDs) with variable size which allow the systematic observation of size dependent carrier capture processes from the barriers into the low dimensional wire/dot region.

EXPERIMENTAL

For the fabrication of quantum wires and quantum dots we started with a high quality MBE-grown GaAs/Al0.38Ga0.62As structure with a 3.8 nm single quantum well (QW) 25 nm below the sample surface. Based on high resolution electron beam lithography we defined wire masks down to 75 nm and dot masks down to 45 nm lateral size to obtain buried nanostructures by masked implantation enhanced intermixing. This method has been described in detail in². The photoluminescence (PL) studies were carried out at low temperature 2 K and 15 K. The measurement of transient spectra was performed either by time resolved single
photon counting with a microchannel plate photo multiplier with a time resolution of 50 ps or a streak camera with a time resolution of 10 ps. The sample was excited by a mode-locked Nd:YAG laser followed by a synchronously pumped dye-laser (pulse width 4...7 ps) or by a titanium sapphire laser (pulse width 2 ps), respectively. Both detection principles enable the observation of transient spectra at various delay times after the laser pulse within a certain time window. We determined the time dependent carrier temperature by fitting a straight line to the high energy tail of the logarithmic plot of the dot or wire PL spectrum.

RESULTS AND DISCUSSION

First we studied the hot carrier effect in QWWs and QWDs as a result of carrier capture from the higher dimensionl lateral barrier into the nanostructures. For this experiment the sample was excited nonresonantly (above the lateral barrier). The transient spectra for the narrowest QWD structures of about 45 nm diameter as well as the determined carrier temperatures of different QWDs with various sizes are shown in figure 1.

![Figure 1](image)

**Figure 1.** Transient spectra of 45 nm QWDs (1.68 eV) and the corresponding lateral barriers (1.73 eV) at various delay times after the laser pulse (left) and the evaluated carrier temperatures for different QWDs (right) vs. delay time.

The spectra (fig. 1 left side) show directly the processes of carrier capture and relaxation in systems with different dimensionality. The low dimensional quasi 0D system cools slower compared to the 2D barrier. Even for rather long delay times ~ 800 ps the QWDs (emission at 1.68 eV) appear overheated compared to the barrier (emission at 1.73 eV) indicated by the different slopes of the high energy tail in both spectra. This hot carrier effect scales with the size of the structures (fig. 1 right side). We find very high initial carrier temperatures in narrow QWDs compared to wider QWDs. And again in agreement with the qualitative finding taken from the direct view of the spectra we observe elevated carrier temperatures in smaller structures for long delay times > 800 ps. To obtain a separation of both the hot carrier effect caused by the carrier capture and the hot carrier effect caused by relaxation bottlenecks we performed an additional experiment. The sample excitation was carried out resonantly (below the lateral barrier) but with the same photon flux density. From the experimentally determined temperatures after resonant (T_res) and nonresonant (T_nonres) excitation we calculated the temperature difference \( \Delta T = T_{\text{nonres}} - T_{\text{res}} \) for each structure as a function of time shown in fig. 2. Comparing wire (fig. 2 left side) and dot structures (fig. 2 right side) we observe as a striking feature a strong difference in \( \Delta T \)-values between the wire and the dot systems.