Photocapacitance of selectively doped AlGaAs/GaAs heterostructures containing deep traps

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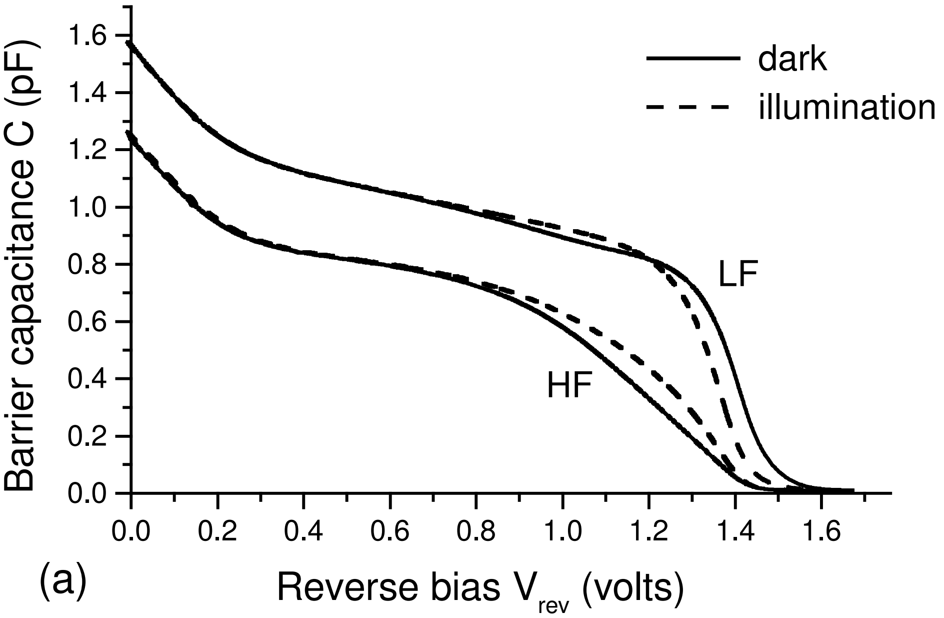
AlGaAs/GaAs HEMT heterostructures have a doping step at the heterointerface and usually contain deep donors (*DX* centers) in the AlGaAs layer. As we showed earlier by the example of MESFET structures, steep dopant gradients in combination with the presence of deep traps may radically alter the behavior of such an important characteristic as photocapacitance in comparison with graded dopant profile structures, for which the majority of existing photocapacitance techniques have been developed. The goal of this paper is to study the photocapacitance of normal selectively doped AlGaAs/GaAs heterostructures with deep donor traps in the AlGaAs layer.

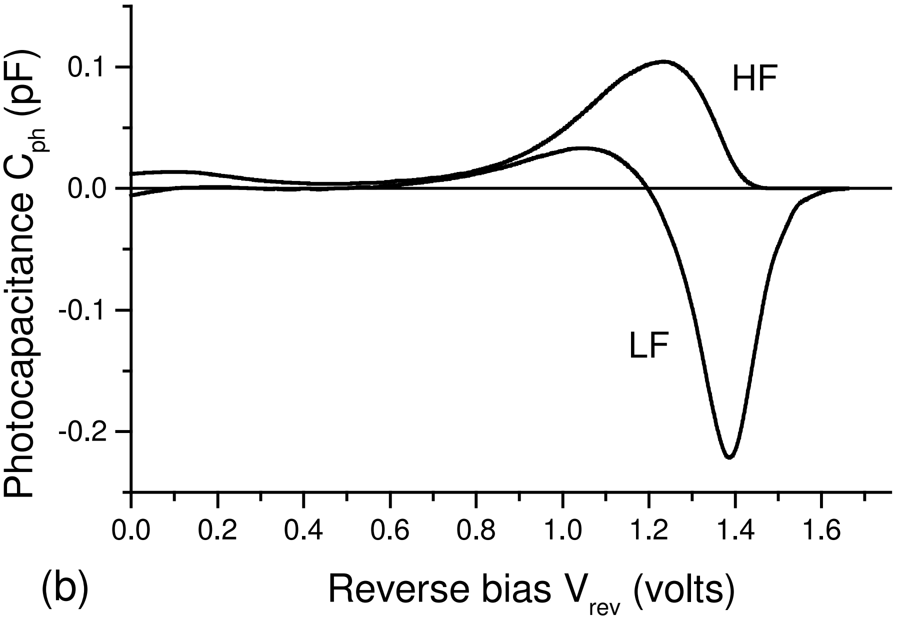
We report on a procedure for the calculation of the low- and high-frequency barrier capacitances of such heterostructures, which accounts for the entire 2DEG energy spectrum and dispenses with the depletion approximation for the AlGaAs layer. These capacitances are calculated in the dark and under extrinsic illumination. Typical calculated low-frequency (LF) and high-frequency (HF) capacitances and photocapacitances are shown in the figure. As seen, the HF and LF photocapacitances have the form of a positive peak and that of a positive peak followed by a negative valley, respectively.

Such behavior of the photocapacitance may be understood as follows. The peaks are due to the photoionization of deep traps in the AlGaAs layer providing an additional inflow of free carries into the quantum well. Because of this, under illumination the steeply decreasing region of the *C*-*V* curve (associated with quantum well emptying) starts at a higher reverse bias than in the dark. As the reverse bias is increased, the AlGaAs layer becomes nearly depleted of free carriers and the quantum well becomes nearly emptied. From this point on, the predominant contribution to the LF barrier capacitance is caused by the variation of the trapped charge at the edge of the Schottky barrier depletion region in the AlGaAs layer with reverse bias. Under illumination, the density of this trapped charge decreases, and its decrease approaches zero in two limiting cases: (1) when the free carrier density at the edge of the Schottky barrier depletion region is so high that the deep traps situated there are all occupied even under illumination; (2) when this free carrier density is so low that the traps are all empty. As a consequence, the LF photocapacitance at high reverse biases is negative and passes through a minimum.

The photocapacitance of GaAs MESFET structures behaves similarly, though their physics is quite different from that of HEMT structures. For both device types, the photocapacitance behavior is linked to the presence of a built-in space charge region stemming from a steep impurity gradient. This suggests that the extrinsic photocapacitance of any semiconductor structure with deep traps and a steep impurity gradient will behave in a similar way.


Barrier capacitance C (pF)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
dark
illumination
LF
HF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Reverse bias V_{rev} (volts)

(a)


Photocapacitance C_{ph} (pF)
0.1
0.0
-0.1
-0.2
HF
LF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Reverse bias V_{rev} (volts)

(b)