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I-V And C-V Characteristics of nGaAs-nInSb Heterojunctions Obtained by Pulsed Laser Deposition Technique

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ABSTRACT

Using pulsed laser deposition technique, nGaAs-nInSb heterojunctions (HJs) are obtained. Their electrical properties are studied. The Current-Voltage characteristics show that obtained HJs possess rectifying properties. The rectification coefficient depends strongly on the doping level of GaAs substrate. The linear dependence of C^{-2} (V) curve in Capacitance-Voltage characteristics, as well as the change of photo-response sign with wavelength, indicates that the HJs have abrupt interface, which is, to the best of our knowledge, a novel result for these HJ materials. The full number of interface states arising due to the lattice mismatch is determined which is in agreement with Hall measurements. Current-Voltage characteristics of obtained HJs are analogous to those of metal-semiconductor junction. Based on the obtained results the energy band diagrams of nGaAs-nInSb HJ is constructed taking into account the interface states.

INTRODUCTION

Owing to its many advantages (such as technology flexibility, low temperature of crystalline growth, as well as production of thin and ultrathin layers of actually any material) the pulsed laser deposition (PLD) has its leading role in fabrication of thin semiconductor materials. In recent years, a growth of interest is observed in using the PLD for production of semiconductor heterojunctions (HJ).

Due to a large lattice mismatch (~14%) the nInSb-nGaAs type HJs refer to the class of non ideal HJs. Earlier, E.D. Hinkley and R.H. Rediker [1] reported the fabrication of nGaAs-nInSb HJs obtained by fusion of InSb into the GaAs. Nevertheless, there are no reports to our knowledge on the fabrication of crystalline nInSb-nGaAs HJs with abrupt interface using the usual techniques. This might be due to the difficulty of crystalline growth of HJ materials with large lattice mismatch. Only recently, in [2] the possibility of fabrication of crystalline nInSb-nGaAs HJs with abrupt interfaces was shown, and the results were used for analysis of an infrared (~5-6 μm) pyrometer. However, the electrical characteristics of these HJs were not presented in [2].

In the present work, crystalline nGaAs-nInSb HJs are fabricated based on the PLD technique, and their electrical properties are studied.

EXPERIMENT

The facility for fabrication of nGaAs-nInSb HJs included a Q-switched laser on Nd^{3+} (pulse length is 30 nsec., energy per pulse is 1 J, intensity in the irradiation area of the target is ~10^8 W/sm^2) and a vacuum chamber with residual pressure of ~10^{-6} Torr. Polished nGaAs slabs with various doping degrees ($5 \cdot 10^{16}$–$5 \cdot 10^{18}$ sm^{-3}) were used as substrates, and nInSb pellets with doping degree 10^{14} sm^{-3} were used as target material. The nInSb layers

with ~0.1μm thickness were deposited in vacuum of ~10^{-6} Torr at temperature of crystalline growth of ~350 ^{0}C. A shell of width ~6 Å was deposited after each evaporating pulse. The back contact to the nGaAs substrate was made up by thermal spraying of In with protecting Ag layer and the structure was annealed during the deposition of nInSb layer. The crystallinity of the layers was checked by electron-diffraction method. In order to obtain current-voltage (I-V) and capacitance-voltage (C-V) characteristics the produced nGaAs-nInSb structures were split and placed in a purpose-built holder. All measurements were carried out at room temperature.

RESULTS AND DISCUSSION

The I-V characteristics of produced HJs at various doping levels of GaAs are shown in figure1. As it is seen, the HJs possess rectifying properties, and the rectification coefficient depends strongly on the substrate doping level. For an HJ with N_D(GaAs)≈$5x10^{16}$ sm^{-3} the rectification coefficient, k≈10^6 at 0.7 V, while for N_D(GaAs)≈$5x10^{18}$ sm^{-3} k≈40 at the same voltage.

In figure 2, the C-V characteristics of HJs are represented at various doping levels. The essentially linear dependence of the experimental curve, C^{-2}(V), is an evidence of the abruptness of the HJ interface.

The carrier concentrations in GaAs were determined from the slope of the C^{-2}(V) curve. The results are in reasonable agreement with Hall measurements of concentrations in nGaAs. The extrapolation of C^{-2}(V) dependence to the value C^{-2}=0 gives one the contact potential falling on the nGaAs. Based on these results the total equilibrium charge ($Q_{is}=-2qEN_DV_D$) on interface states originating due to the lattice mismatch, as well as the total number of these states per unit area were determined. Results are given in Table 1.
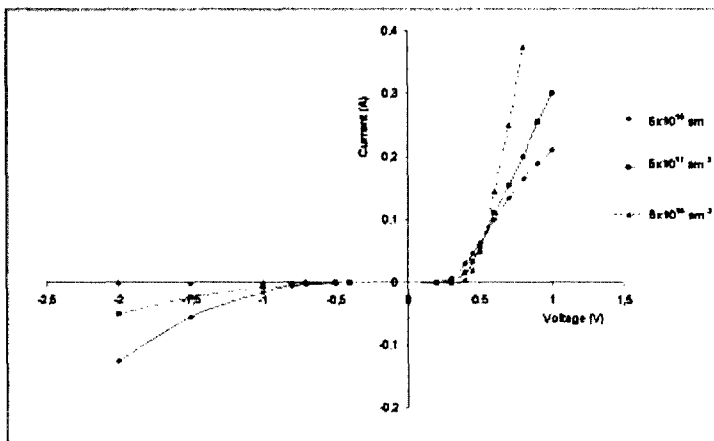

Figure 1. I-V characteristics of heterojunction nGaAs-nInSb at various doping levels of nGaAs.
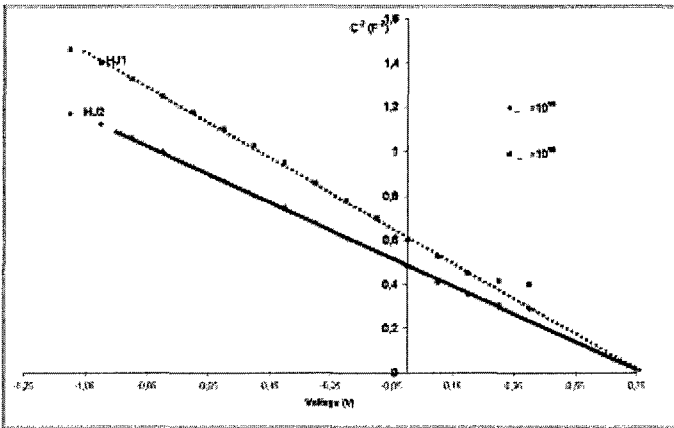
Figure 2. C-V characteristics of nGaAs-nInSb heterojunction at various doping levels of nGaAs.

Table I. Main experimental results obtained from I-V and C-V characteristics.

	N_D(GaAs) sm^{-3} Hall measur.	N_D(GaAs) sm^{-3} from C-V curves	N_{is} theor. sm^{-2}	N_{is} exper. sm^{-2}	qV_D(eV) from C-V curves	Ψ(eV) from C-Vcurve	η,from I-V curves	HJ surf. area (sm^2)
HJ1	$5\cdot10^{16}$	$6,3\cdot10^{16}$	$3\cdot10^{14}$	$\geq 1,6\cdot10^{14}$	0,75			$5\cdot10^{-3}$
HJ2	$5\cdot10^{17}$	$4,8\cdot10^{17}$	$3\cdot10^{14}$	$\geq 4,6\cdot10^{14}$	0,75	0,74	2,25	$5\cdot10^{-3}$

As it is seen, the obtained values of N_{is} are in good agreement with the total number of interface states of nGaAs-nInSb HJ, which was estimated from simple considerations based on the lattice mismatch of HJ materials.

The appearance of interface states also affects strongly on the mechanism of current flow through the HJ. In figure 3, the I-V characteristics of nGaAs-nInSb HJ with N_D(GaAs)$\approx5\cdot10^{17}$ sm^{-3} at room temperature is represented.
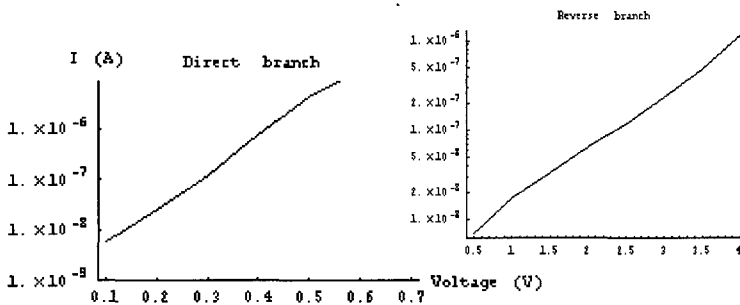

Figure 3. I-V characteristics of heterojunction nGaAs-nInSb with doping level of GaAs $N_D\sim5\times10^{17}$ at room temperature.
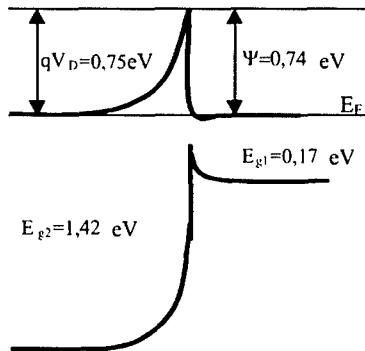
Figure 4. Energy band profile of nGaAs-nInSb heterojunction taking into account the interface states.

In spite of the large number of interface states the saturation of current was not observed in any direction. The I-V characteristics of studied HJs are similar to those of metal-semiconductor junctions.

The direct current is described by an expression $I=I_0 \cdot (exp(qV/\eta kT)-1)$, where $I_0=A*T^2 \cdot exp(-\Psi/\eta kT)$ (A=8.64 A·sm^{-2}/^{0}K^{-2}, A is the effective Richardson constant, Ψ is the metal-semiconductor barrier, η is the imperfection coefficient).

The values of η and Ψ deduced from I-V curves are given in Table1. The value of Ψ agrees well with the barrier height determined from C-V characteristics. The results of I-V and C-V characteristics were used to construct the energetic band diagram of nGaAs-nInSb HJ, which takes into account the interface states (figure 4).

CONCLUSIONS

We have studied the current-voltage and capacitance voltage characteristics of heterojunctions nGaAs-nInSb obtained by pulsed-laser deposition. We have shown that produced HJs have abrupt interfaces and posses rectification properties, which depend on the doping level of nGaAs substrates. The current transmission through HJ is similar to that through a metal-semiconductor junction. The energy band diagram of nGaAs-nInSb is constructed based on the obtained results.

REFERENCES

1. E. D. Hinkley, R. H. Rediker, Solid State Electronics, v. 10, 671 (1967).

2. A.G. Alexanian et al. The Int. Journ. IR and MM Waves, v. 18, N1 (1997).