2.4 μm cutoff wavelength AlGaAsSb/InGaAsSb phototransistors

O.V. Sulima, K. Swaminathan, T.F. Refaat, N.N. Faleev, A.N. Semenov, V.A. Solov'ev, S.V. Ivanov, M.N. Abedin, U.N. Singh, D. Prather

We report the first AlGaAsSb/InGaAsSb phototransistors with a cutoff wavelength (50% of peak responsivity) of 2.4 μm operating in a broad range of temperatures. These devices are also the first AlGaAsSb/InGaAsSb heterojunction phototransistors (HPT) grown by molecular beam epitaxy (MBE). This work is a continuation of a preceding study, which was carried out using LPE (liquid phase epitaxy)-grown AlGaAsSb/InGaAsSb/GaSb heterostructures. Although the LPE-related work resulted in the fabrication of an HPT with excellent parameters [1-4], the room temperature cutoff wavelength of these devices (≈ 2.15 μm) was determined by fundamental limitations implied by the close-to-equilibrium growth from Al-In-Ga-As-Sb melts. As the MBE technique is free from the above limitations, AlGaAsSb/InGaAsSb/GaSb heterostructures for HPT with a narrower bandgap of the InGaAsSb base and collector – and hence sensitivity at longer wavelengths (λ) - were grown in this work. Moreover, MBE - compared to LPE - provides better control over doping levels, composition and width of the AlGaAsSb and InGaAsSb layers, compositional and doping profiles, especially with regard to abrupt heterojunctions. The new MBE-grown HPT exhibited both high responsivity *R* (up to 2334 A/W for λ = 2.05 μm at –20ºC.) and specific detectivity *D** (up to $2.1\text{x}10^{11}\text{cmHz}^{1/2}/\text{W}$ for λ = 2.05 μm at –20ºC).

Introduction: The spectral range 2.0 – 2.4 μm wavelength is of great interest for several important applications, including profiling of atmospheric CO_2 using light detection and ranging (LIDAR) techniques [5,6], and non-invasive monitoring of blood glucose using absorption spectroscopy [7]. In this work, the MBE-grown AlGaAsSb/InGaAsSb solid alloys are used for the first time to fabricate HPT providing a high internal gain at the wavelength as long as 2.4 μm. Moreover, the new high-gain phototransistors operate at low bias (less than 1.5 volts).

Experimental: The HPT mesa structure (Fig.1) fabricated and studied in this work is composed of $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$ and $In_{0.18}Ga_{0.82}As_{0.17}Sb_{0.83}$ layers with room-temperature bandgaps of $Eg \approx 1.0$ eV and $Eg \approx 0.54$ eV, respectively. The layers are lattice-matched to a GaSb substrate and were grown at 500°C on an n^+- GaSb (001) substrate using a Riber 32 solid source MBE. A valved cracker source for arsenic (As_4) and a conventional effusion source for antimony (Sb_4) were used. The growth started with a 0.15μm-thick n^+- GaSb buffer layer and was completed with a 0.1μm-thick n^+- GaSb contact layer doped with Te. The HPT structure includes a 0.5μm-thick n-type AlGaAsSb emitter, 0.8μm-thick p-type composite base consisting of AlGaAsSb (0.3 μm) and InGaAsSb (0.5 μm) layers, and a 1.5μm - thick n-type InGaAsSb collector. Mesa HPT with a 400-μm diameter total area and a 300-μm diameter active area were defined using photolithography and wet chemical etching. A backside planar and frontside annular ohmic contact (together with a bonding pad) were deposited by electron-beam evaporation of Au/Ge. A polyimide coating (HD Microsystems PI-2723 photodefinable polyimide resin) was spun on the front of the device. The polyimide served several functions including planarization of the top surface, mesa isolation, and edge passivation.

After dicing, 1-mm^2 pieces with a single device in the middle of each square were mounted to TO-18 headers using silver conducting epoxy and wire-bonded. No antireflection coatings were applied.

Results: Spectral response, dark current and noise measurements were performed for MBE-grown phototransistors. Measurements of spectral response were carried out using the equipment described in Ref. [4]. Fig.2 shows spectral response of an AlGaAsSb/InGaAsSb HPT at the specified bias voltage and +20^{o}C. As can be seen in Fig.2, responsivity R rapidly increases with applied bias voltage and at 1.4 V reaches 1128 A/W for λ = 2.04 - 2.08μm. Even higher values of R (up to 2334 A/W) were measured at -20^{o}C at 1.4 V for λ = 2.05 μm. Fig. 3 shows responsivity R of an AlGaAsSb/InGaAsSb HPT at λ = 2.05 μm vs. bias voltage at temperatures from -20^{o}C to +100^{o}C. One can distinguish two parts of the graph: at very low voltage (< 1V) higher R was measured at higher temperatures, while at higher voltages the opposite dependence was observed. This complicated behavior can be explained by temperature dependencies of minority-carrier (electrons) diffusion length in the base, and by the as-yet-unexplored temperature-sensitive band discontinuities of AlGaAsSb/InGaAsSb heterojunctions, which can affect the minority carrier injection at the emitter-base junction and consequently the gain of the HPT. On the other hand, the dark current and hence the noise current I_n of the HPT are also dependent on applied voltage and temperature. All the above dependencies are considered in specific detectivity $D*$, which is one of the main figures of merit for any photodetector:

$$D^*(T,V) = R(T,V)\cdot\sqrt{A}\big/I_n(T,V)\,, \qquad (1)$$

where A is the detector area.

Fig. 4 exhibits a 2.05-μm detectivity *D** of an AlGaAsSb/InGaAsSb HPT at –20ºC and +20ºC vs. bias voltage. D* value as high as 2.1×10^{11} cmHz$^{1/2}$/W was determined at –20ºC and 1.3 V.

We believe the significant performance levels achieved with the first MBE-grown HPT structures bode well for the AlGaAsSb/InGaAsSb HPT approach to mid-infrared detectors, as well as for the materials and device fabrication technology described here. Moreover, we believe there is much room for further improvements in both *R* and *D** of the AlGaAsSb/InGaAsSb HPT through continued optimization of the design and fabrication.

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Author's affiliations:

O.V. Sulima, K. Swaminathan, N.N. Faleev, D. Prather (Department of Electrical and Computer Engineering, University of Delaware, 140 Evans Hall, Newark, DE 19716, USA)

T.F. Refaat (Science and Technology Corporation, Hampton, VA 23666, USA)

A.N. Semenov, V.A. Solov'ev and S.V. Ivanov (Ioffe Institute, 26 Polytechnicheskaya, St. Petersburg, Russia, 194021

M.N. Abedin and U.N. Singh (NASA Langley Research Center, Hampton, VA 23681, USA)

E-mail address of the corresponding author is osulima@udel.com

Figure captions:

Figure 1. Structure (cross-section) of the fabricated AlGaAsSb/InGaAsSb HPT

Figure 2. Spectral response of an AlGaAsSb/InGaAsSb HPT at the specified bias voltage and +20^{o}C

Figure 3. Responsivity of an AlGaAsSb/InGaAsSb HPT at λ = 2.05 μm vs. bias voltage at specified temperatures

Figure 4. A 2.05-μm detectivity D* of an AlGaAsSb/InGaAsSb HPT at –20ºC and +20ºC vs. bias voltage

Figure 1

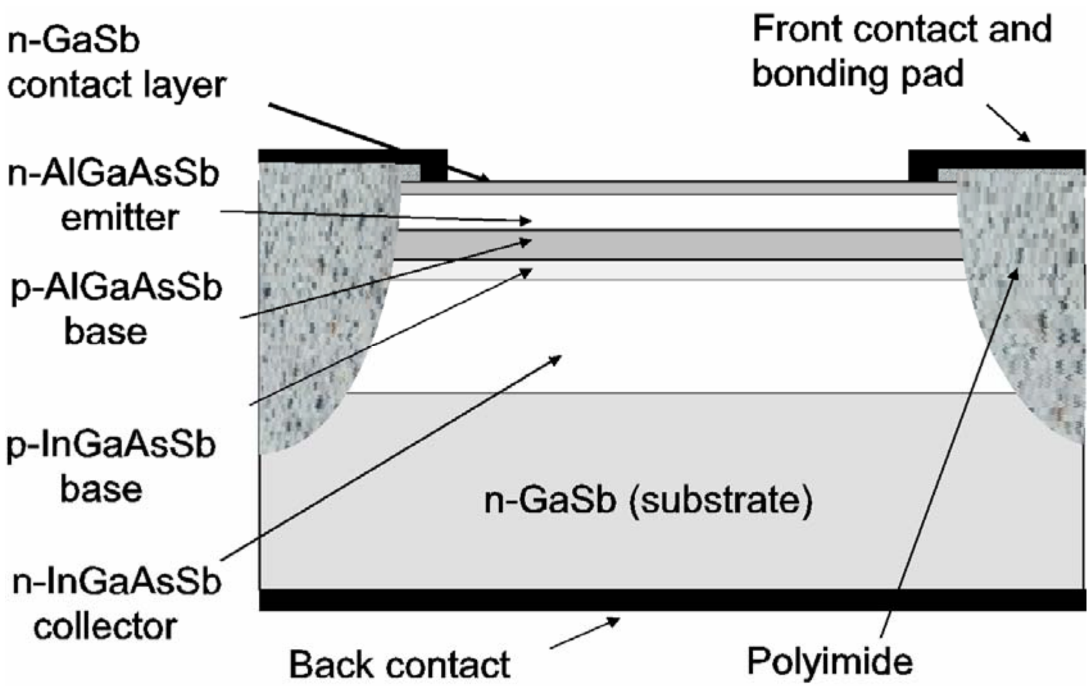

n-GaSb
contact layer
Front contact and
bonding pad
n-AlGaAsSb
emitter
p-AlGaAsSb
base
p-InGaAsSb
base
n-GaSb (substrate)
n-InGaAsSb
collector
Back contact
Polyimide

Figure 2

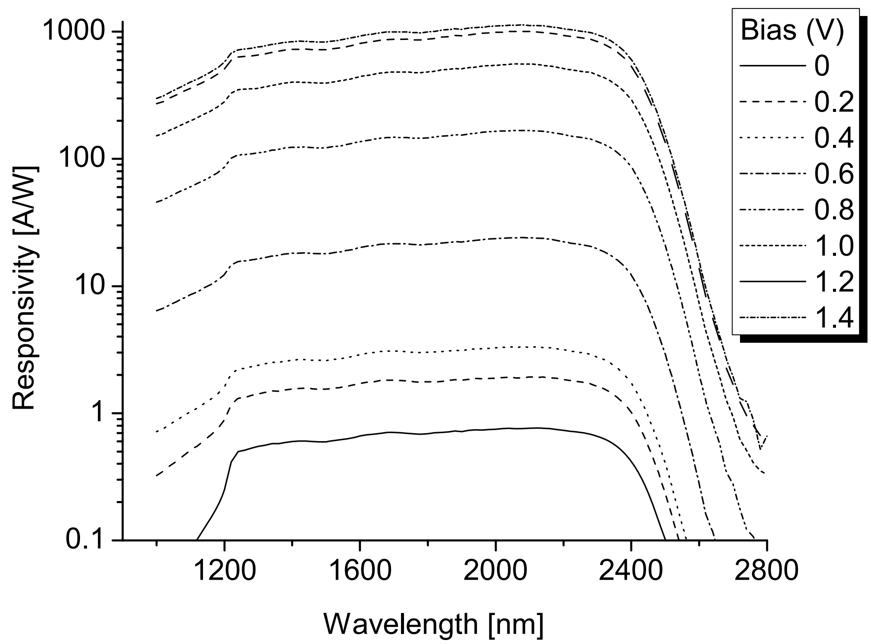

Bias (V)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1000
100
10
1
0.1
Responsivity [A/W]
1200
1600
2000
2400
2800
Wavelength [nm]

Figure 3

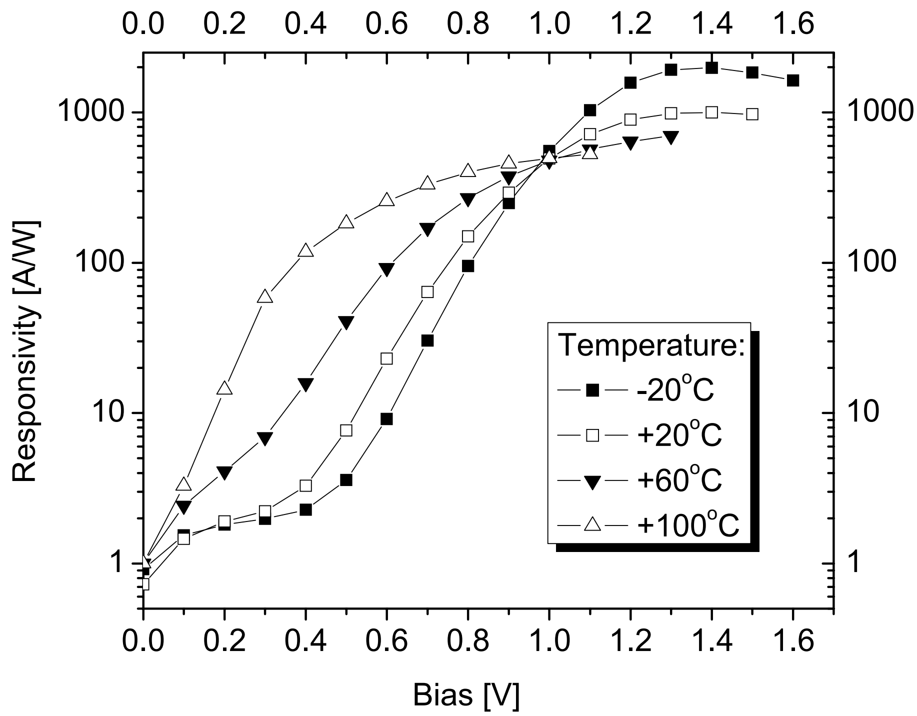
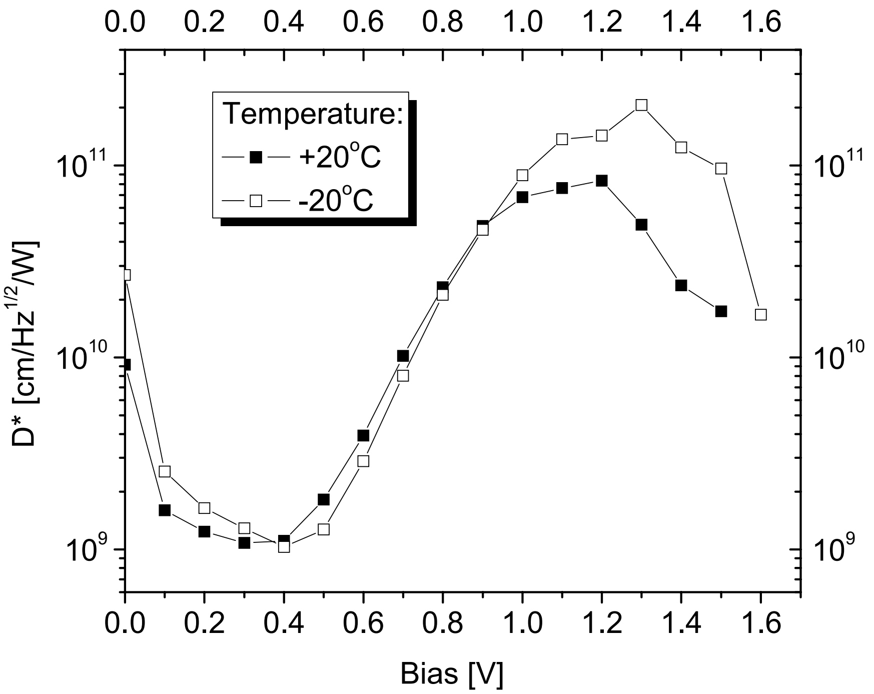

0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1000
100
10
1
Responsivity [A/W]
Bias [V]
Temperature:
-20°C
+20°C
+60°C
+100°C

Figure 4



Temperature:
+20°C
-20°C
D* [cm/Hz^1/2/W]
Bias [V]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
10^9
10^10
10^11