Vol. **107** (2005) *ACTA PHYSICA POLONICA A* No. 2

Proceedings of the 12th International Symposium UFPS, Vilnius, Lithuania 2004

High Power Microwave Detection in Asymmetrically Shaped n-Al$_x$Ga$_{1-x}$As Structures

S. Ašmontas*, A. Čerškus, J. Gradauskas, J. Kundrotas,
A. Lučun, V. Petkun, A. Sužiedėlis and A. Šilėnas

Semiconductor Physics Institute, A. Goštauto 11, 01108 Vilnius, Lithuania

Investigations of detection of high power microwaves in planar asymmetrically shaped microwave diodes on the basis of Al$_x$Ga$_{1-x}$As ternary semiconductors with various AlAs mole fraction are presented. The principle of operation of the microwave diodes is based on carrier heating phenomena in asymmetrically shaped homogeneous semiconductor structure due to different distribution of the electric field strength along the sample. Experimental results of microwave detection on the barrier-less asymmetrically shaped diodes are presented paying special attention to the homogeneity of Al$_x$Ga$_{1-x}$As which was monitored by photoluminescence technique.

PACS numbers: 07.57.Kp, 84.40.–x, 72.20.Ht

1. Introduction

Recent increased interest in the detection of high power microwaves (HPM) is stipulated by the needs of electronic countermeasure systems. The detection of HPM signals raises specific requirements for the microwave (MW) detector. Usually, it must be able to detect and measure high power and short pulses of electromagnetic radiation over a wide frequency range. Detection properties of n-type silicon structure with asymmetrically shaped n–n^+ junction as well as of homogeneous semiconductor fabricated on the base of a single crystal wafer of the same semiconductor revealed the ability to measure directly MW power up to 8 kW in X-frequency range [1]. On the other hand, investigations of MW detection features of whisker-contacted GaAs/AlGaAs heterojunctions showed higher voltage sensitivity of the diodes in comparison with the homojunction ones as well as demonstrated good burn-out resistivity properties of these diodes [2]. Therefore, the asymmetrically shaped planar microwave diode fabricated from Al$_x$Ga$_{1-x}$As ternary semiconductor seems to be a promising detector for HPM application.

---

*corresponding author; e-mail: as@uj.pfi.lt

Experimental results on the detection properties of homogeneous asymmetrically shaped semiconductor structure of $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ with various x are presented in this paper. Measurements were performed at room temperature in X (10 GHz) frequency range.

2. Samples

Schematic view of the asymmetrically shaped MW diode is depicted in Fig. 1. Liquid phase epitaxy technique was used to grow thick (20 μm) AlGaAs epitaxial layer and following Te-doped thin (≈ 1 μm) n^+-AlGaAs epitaxial layer for ohmic contacts. Large interval of cooling temperature is required for growth process of thick epitaxial $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ layer. Therefore, growth process was divided into three cooling temperature intervals of 30 degrees for the minimization of the change of x along the growth direction. A new saturated melt was used in every interval of epitaxial growth. AlAs mole fraction x in the epitaxial layer was kept nearly constant and ranged from 0.19 to 0.36 for separate samples.

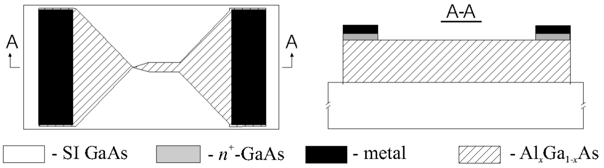

Fig. 1. Schematic view and cross-section of asymmetrically shaped MW diode on the base of homogeneous AlGaAs layer.

The fabrication process of barrier-less asymmetrically shaped planar diode started by plasma-chemical deposition of SiO_2 film onto chemically cleaned surface of the epitaxial layer. The first photolithography step opened the windows in SiO_2 film, which was followed by Ge/Ni/Au thermal evaporation. Annealing of the evaporated metals at $T = 425°\mathrm{C}$ in Ar atmosphere has formed the ohmic contacts. In the second photolithography step a pattern for mesa formation of the MW diode was prepared. Deep mesa was formed in the diode when the epitaxial layers were etched through, up to the semi-insulating substrate. The third photolithography step was performed to protect ohmic contacts during chemical removing of the conductive n^+-GaAs layer. The diodes were mounted into rectangular waveguide of lowered height.

3. Results and discussion

Figure 2a depicts the voltage–power characteristics of the asymmetrically shaped barrier-less diodes. The hot carrier bigradient effect is mainly responsible for induced voltage across the diode (see Ref. [3] and literature cited herein). The polarity of the detected voltage is in agreement with the bigradient electromotive force (emf). The highest voltage sensitivity was measured for the diodes with

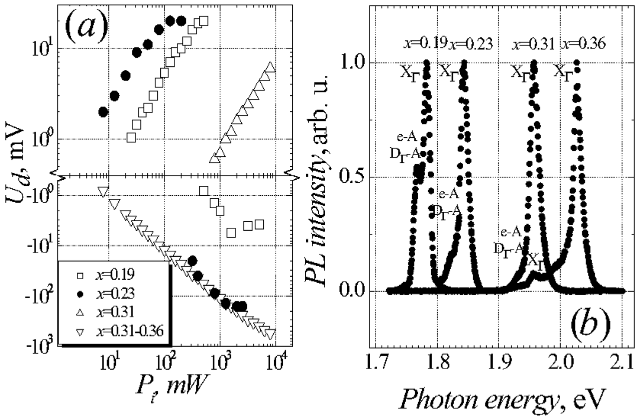

Fig. 2. Voltage power characteristics of barrier-less MW diodes on the base of n-type $Al_xGa_{1-x}As$ with different AlAs mole fraction x values (a) and PL spectra of the layers (b).

$x = 0.23$, while the lowest one was observed for $x = 0.31$. Substantially lower carrier concentration ($n = 7 \times 10^{15}$ cm^{-3}) that was accompanied by slight decrease in electron mobility ($\mu_0 = 1800$ cm^2 V^{-1} s^{-1}) in $Al_{0.23}Ga_{0.77}As$ layer compared with that in $Al_{0.19}Ga_{0.81}As$ ($n = 3 \times 10^{16}$ cm^{-3}, $\mu_0 = 4020$ cm^2 V^{-1} s^{-1}) gave a more effective separation of electric charge in the device and, as a result, greater electromotive force in the asymmetrically shaped semiconductor structure. However, in the case of $x = 0.31$ ($n = 4 \times 10^{15}$ cm^{-3}), a significant decrease in the electron mobility ($\mu_0 = 620$ cm^2 V^{-1} s^{-1}) worsened the conditions for the bigradient emf to originate. On the other hand, a substantial increase in electrical resistivity of the semiconductor lowered the portion of MW power absorbed by the diode by approximately one order of magnitude. This consideration explains the observed increase in the upper dynamic range limit of the diodes based on n-type $Al_{0.31}Ga_{0.69}As$. Low values of the upper dynamic range limit of the diodes based on $Al_xGa_{1-x}As$ with $x = 0.19$ and $x = 0.23$ were caused by the change of the detected voltage polarity as MW power was increased. In some cases the polarity of the detected voltage was opposite to that of the bigradient emf in a whole microwave power range (see, for example voltage power characteristic represented by down triangle marks in Fig. 2a).

In order to understand these peculiarities, the photoluminescence (PL) spectra of $Al_xGa_{1-x}As$ layers excited by Ar-laser light were investigated by a single photon counting method at liquid nitrogen temperature as shown in Fig. 2b. The excitonic PL peaks X_Γ correspond to the forbidden energy gap of $Al_xGa_{1-x}As$ with x equal to 0.19, 0.23, 0.31, and 0.36. Additional peaks were observed in all the investigated materials, but they vanished with the increase in x. We associate these additional peaks with electron transition from conductivity band edge to acceptor level (e–A) and from the donor level to acceptor (D_Γ–A). The energy difference between the X_{Γ} and e–A/D$_{\Gamma}$–A peaks ($20 \div 30$ meV) allows us to identify the acceptor level to be a carbon impurity $\mathrm{C_{As}}$. With increase in AlAs mole fraction, the additional PL peak intensity decreased, which could be explained by change of filling of donor levels. Presence of compensating acceptor impurities in n-type $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ has not only reduced the electron mobility but also enhanced the formation of charge inhomogeneities in the material. That is the reason why it was possible to detect MWs not only in asymmetrically shaped semiconductor structure but also due to charge inhomogeneities [4]. The polarity of the detected voltage due to inhomogeneities can have any sign. If the inhomogeneity-induced voltage had opposite to bigradient emf sign, then the resultant detected signal was smaller, or even had opposite sign, thus, reducing the upper limit of the dynamic range of the diodes as can be seen in Fig. 2a in cases of $x = 0.19$ and $x = 0.23$. A particular attention should be paid to the luminescence spectrum of the MW diode, marked as $x = 0.31-0.36$, with opposite polarity of the detected voltage. Two PL spikes X_{Γ} could be distinguished for different values of AlAs mole fraction, $x = 0.31$ and $x = 0.36$ in this case. This implies that the semiconductor material is polycrystalline in nature. The presence of the semiconductor regions with different x values in the diode structure determines the inter-grain detection mechanism of the diode.

4. Conclusions

The highest limit of the upper dynamic range is ≈ 10 kW for the barrier-less MW diodes on the base of asymmetrically shaped n-type $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ ternary semiconductor. This was achieved with AlAs mole fraction $x = 0.31$. Non-monotonic character of the voltage–power characteristic is inherent to the barrier-less diodes with lower x values; this is explained by existence of electrical charge inhomogeneities in the semiconductor structure.

Polycrystalline nature of the $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ layers with higher value of AlAs mole fraction is responsible for the opposite polarity of the detected voltage. This feature of the microwave diode can be employed for high power MW measurements.

Acknowledgments

This work was supported by EOARD under contract No. FA8655-03-1-3021. Authors are grateful to G. Steikūnas and A. Steikūnienė for the sample fabrication.

References

[1] S. Ašmontas, J. Gradauskas, V. Petkun, A. Sužiedėlis, *Lithuanian J. Phys.* **43**, 345 (2003).

[2] S. Ašmontas, J. Gradauskas, J. Kundrotas, A. Sužiedėlis, A. Šilėnas, G. Valušis, in: *Proc. 24th Int. Conf. on Physics of Semiconductors 24ICPS'98*, Jerusalem (Israel) 1998, Ed. D. Gershoni, CD-ROM (1193.pdf), World Scientific, Singapore 1999.

[3] S. Ašmontas, A. Sužiedėlis, *J. Thermoelectricity* **1**, 5 (1997).

[4] S. Ašmontas, A. Skučienė, *Fiz. Tekh. Poluprovodn.* **27**, 207 (1993).