ИНСТИТУТ
ОПТИКИ АТМОСФЕРЫ
им. В.Е. ЗУЕВА СО РАН

Rad-hard PIN photodiode design studying

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Motivation

The transceiver path for the optical range includes an optical source, an optical modulator and an optical receiver. As an optical receiver, PIN photodiodes are used to convert an optical signal to a microwave signal in the microwave range. When using PIN photodiodes in the upper atmosphere, signal interference can be observed.

Purpose of research

Purpose: To develop the rad-hard PIN-photodiode model operating at a 1550 nm wavelength

Objectives:

1. To review of literature related to rad-hard heterostructure materials
2. To choose the most suitable material
3. To design the PIN photodiode simplest model from the selected material with using COMSOL Multiphysics
4. To estimate simulated PIN photodiode characteristics

Review

- **InP (Indium phosphide) is used in the space in radiophotonic communication system** (J. Klamkin *et al*., "Indium Phosphide Photonic Integrated Circuits: Technology and Applications," *2018 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)*, San Diego, CA, 2018, pp. 8-13, doi: 10.1109/BCICTS.2018.8550947)

- **GaAs/AlGaAs – heretostructures are currently used in solar panels and in some applications in communication systems** Onishchenko E. Semiconductor heterostructures: from classical to low-dimensional, or “Constructor” from a Nobel laureate.

- **InGaAs (Indium gallium arsenide) is considering as promising material for radiophotonic communication systems in space** (Joshi M. et al. «Rad-hard, Ultra-fast, InGaAs Photodiodes for Space Applications», Proceedings of SPIE - The International Society for Optical Engineering 6220, Backnang, Germany, May 2006, DOI: 10.1117/12.666055)

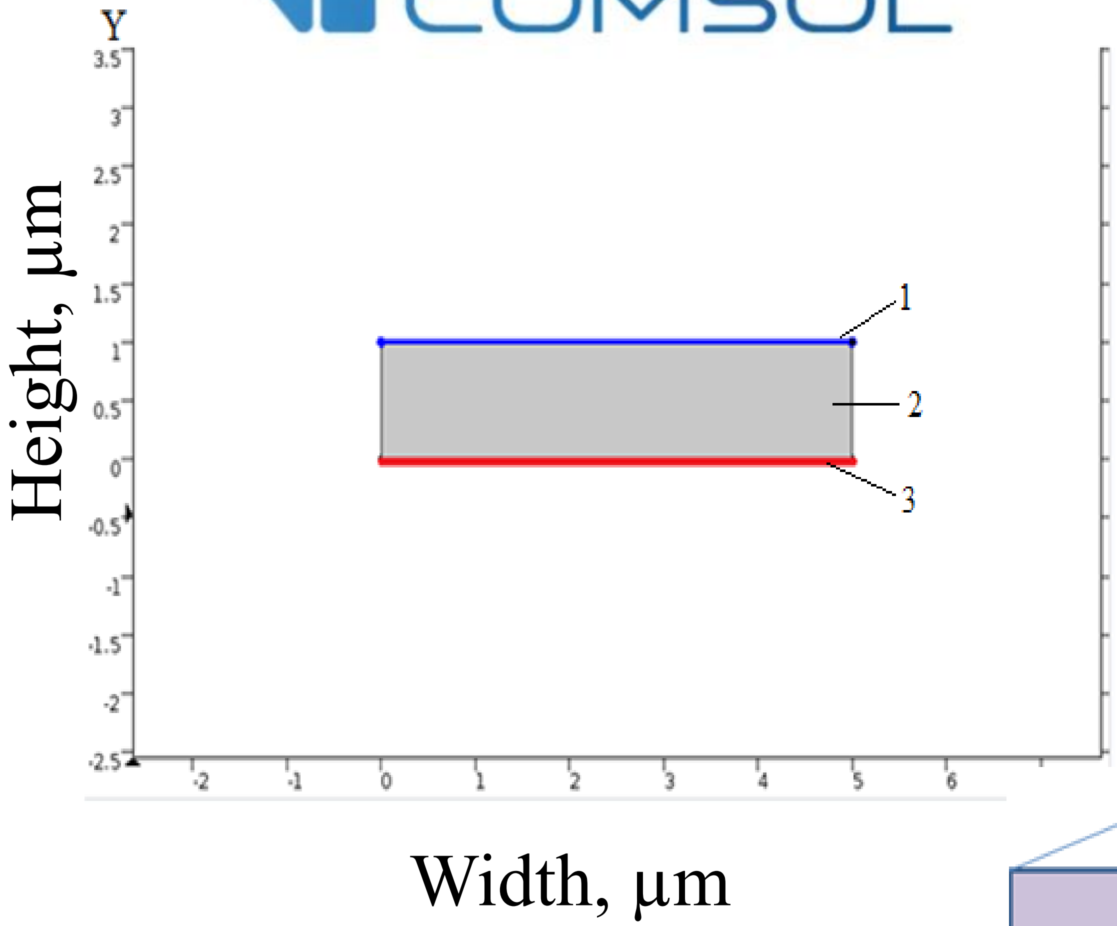
Heterostructure choice

Material / Feature	GaAs	InP	InGaAs	AlGaAs
Band gap at 300 К, eV	1,42	1,34	0,354 – 1,42	1,42 – 2,16
Melting Point, ºC	1238	1062	942 - 1238	1238 - 1740
Specific heat capacity J/(kg*К)	318	310	250-318	330-450

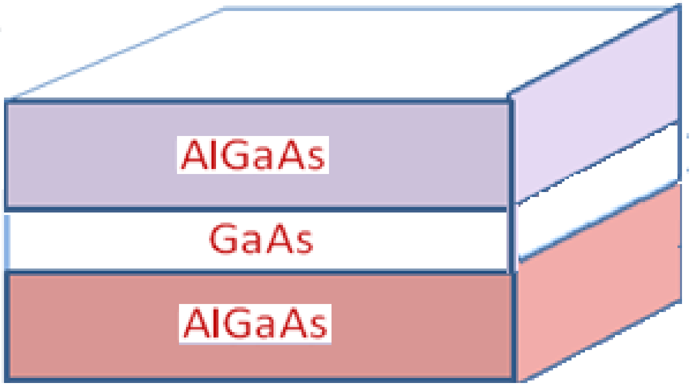
Handbook Series on Semiconductor Parameters, Volume 1. Front Cover. M. Levinshtein. World Scientific, May 1, 1997 - Semiconductors - 300 pages

Heterostructure construction

COMSOL

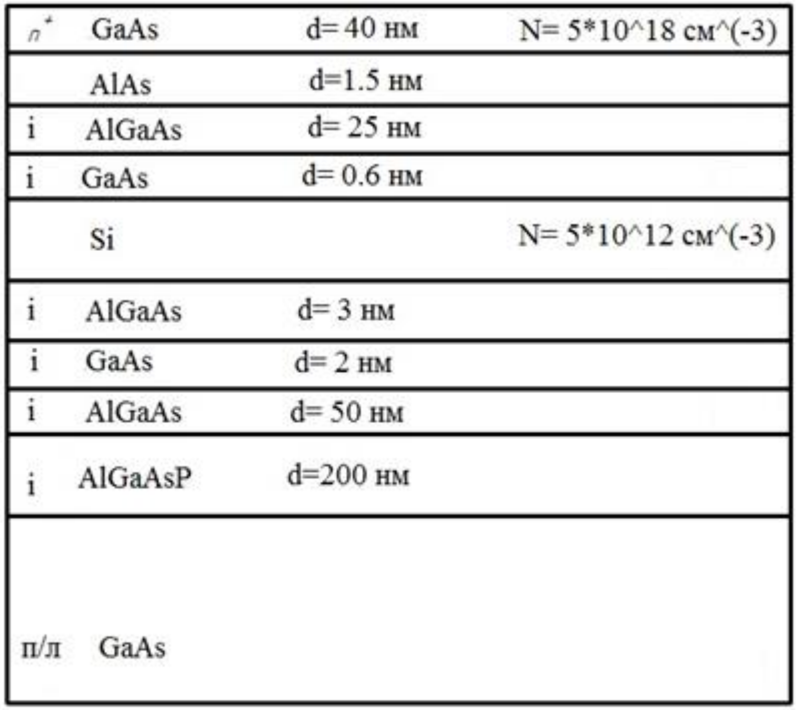


1 – p-region
2 – I - region
3 – n - region



Growing variants

1) PIN photodiode MMIC integration using a highly doped n + region and growing additional i and p + regions;
2) PIN photodiode MMIC integration directly into MMIC with the growing of all three areas (n +, i, p +).

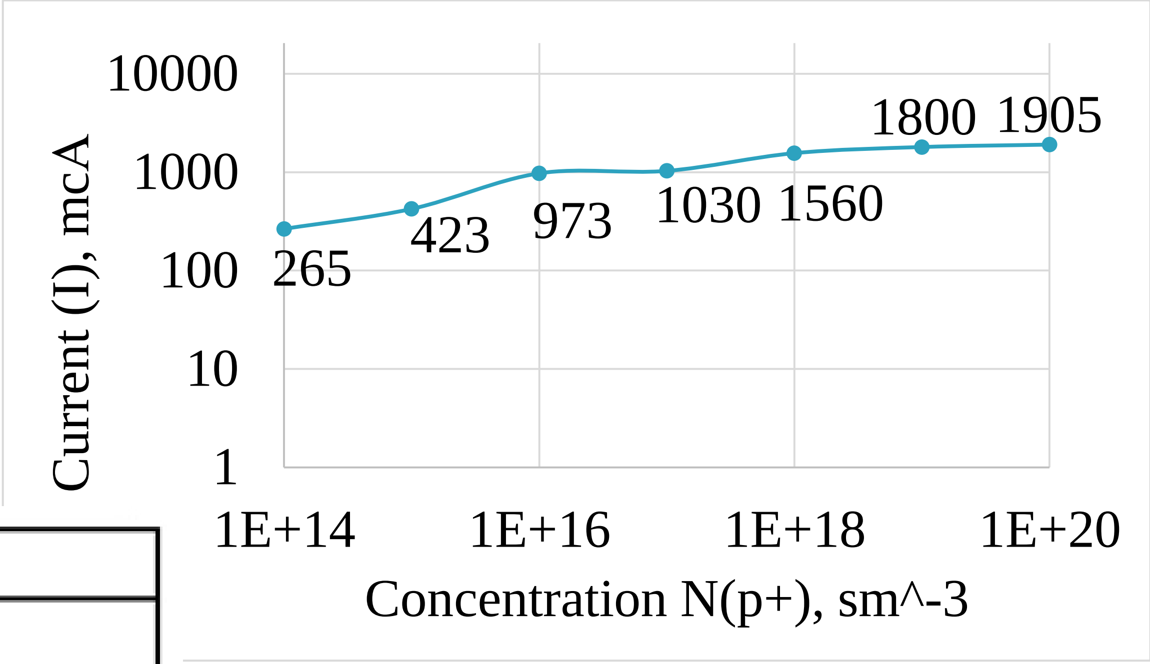


n^+	GaAs	d= 40 нм	N= 5*10^18 см^(-3)
	AlAs	d=1.5 нм	
i	AlGaAs	d= 25 нм	
i	GaAs	d= 0.6 нм	
	Si		N= 5*10^12 см^(-3)
i	AlGaAs	d= 3 нм	
i	GaAs	d= 2 нм	
i	AlGaAs	d= 50 нм	
i	AlGaAsP	d=200 нм	
п/л	GaAs		

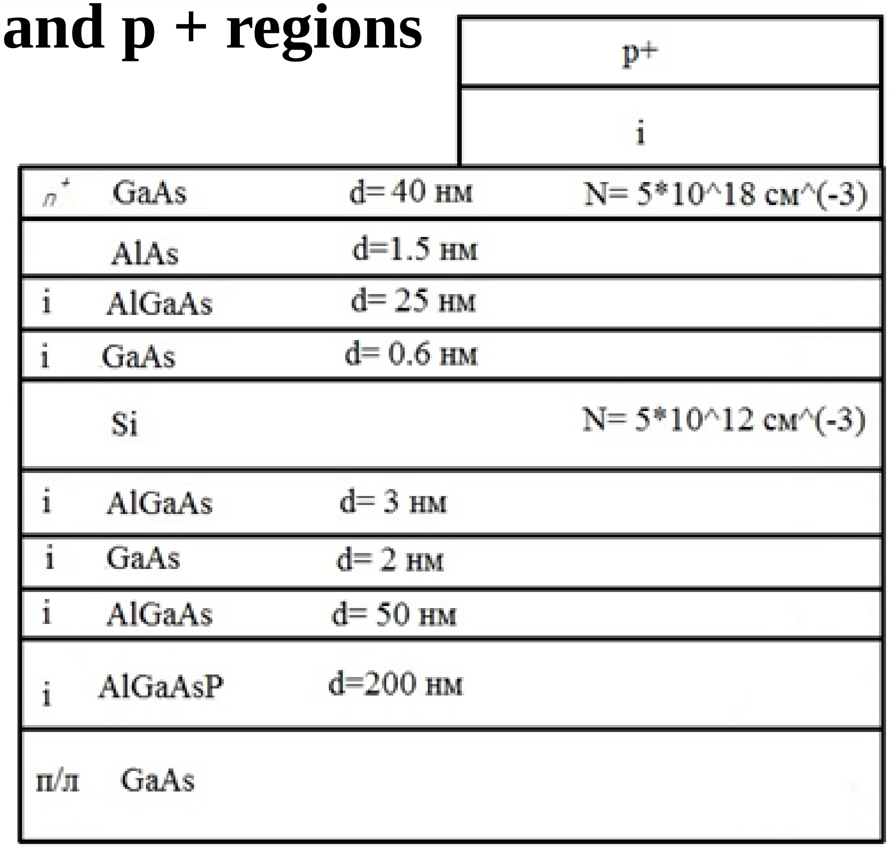
Standard industrial transistor heterostucture

Integration simulation

Integration using a highly doped n + region and growing additional i and p + regions



The dependence of electric current on concentration charge carriers.



p+			
i			
n^+	GaAs	d= 40 нм	N= 5*10^18 см^(-3)
	AlAs	d=1.5 нм	
i	AlGaAs	d= 25 нм	
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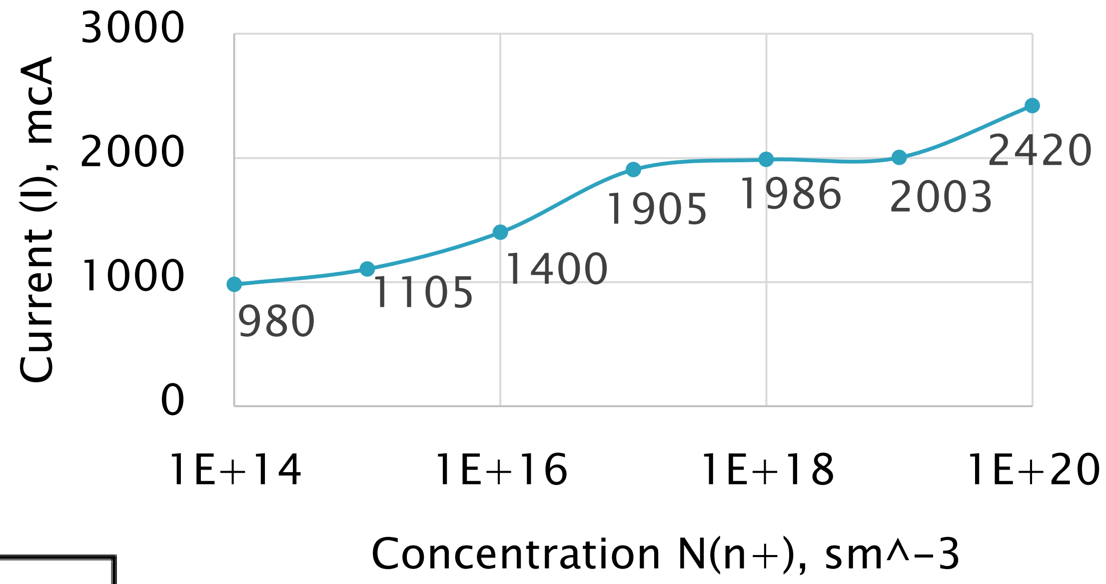
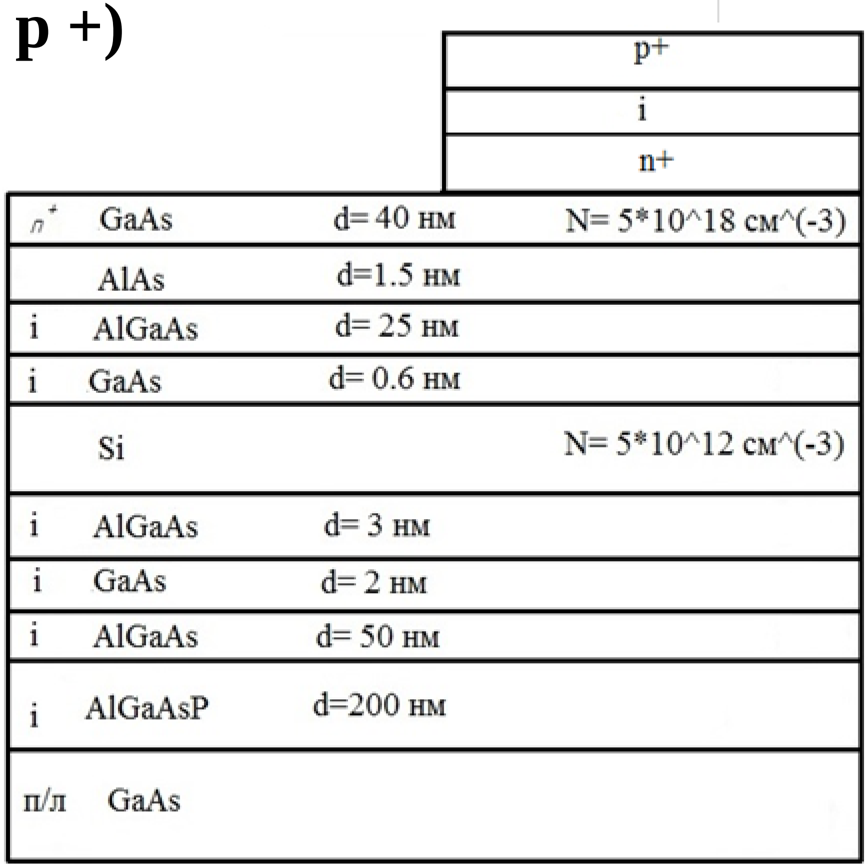
i	AlGaAsP	d=200 нм	
п/п	GaAs		

Integration simulation

Integration directly into MMIC with the growing of all three areas (n +, i, p +)



The dependence of electric current on concentration



	p+		
	i		
	n+		
n^+	GaAs	d= 40 нм	N= 5*10^18 см^(-3)
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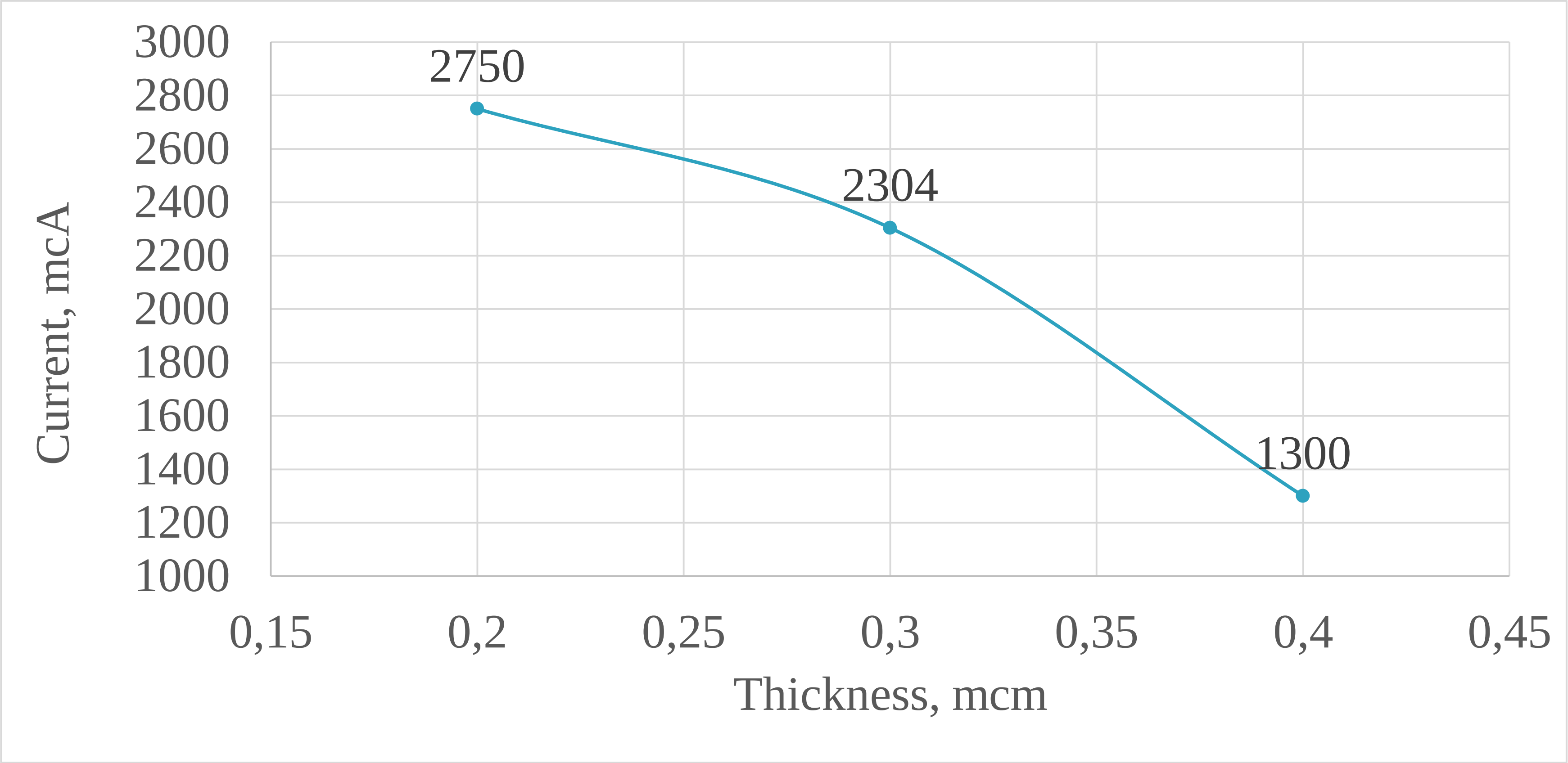
п/л	GaAs		

i-region thickness



Results

- In Comsol Multiphysics the PIN photodiode from GaAs / AlGaAs was simulated and optimal parameters was matched.
- The maximum current value is achieved at concentrations:

  N(i) $=10^{8}$ sm^{-3}, $\mathrm{N(p\ +)} = 10^{20}\ \mathrm{sm}^{-3}$, $\mathrm{N\ (n\ +)} = 10^{18}\ \mathrm{sm}^{-3}$ for the first integration method; for the second integration method N(i)= 10^{8} sm^{-3}, N(p+) $=10^{20}$ sm^{-3}, N(n+) $=10^{20}$ sm^{-3}
- Layers thichnesses for the both integration methods: P – 0,1 mcm, I – 0,3 mcm, N – 0,1 mcm.

Thank you for attention!