Resonant Cavity Enhanced GaInNAs-based Photodetectors with Gain for Operation at 1.3 μm

Project Summary

In order to meet the increasing demand of large volumes of data traffic at high rates over long distances, information is sent as optical signals (short laser pulses) through optical fibres. Optical fibre networks have two wavelength regions (windows) with small attenuation of the optical signals. The first of these is the one at around λ= 1.55 μm which, with the application of wavelength division multiplication (WDM), is already very heavily utilised in long haul communication systems. The second window is centred around λ= 1.3 μm, it has a slightly higher attenuation and therefore suitable for shorter distance (metro and local) networks. The main components of an optical communication system are lasers, modulators, optical fibres optical amplifiers, photo-detectors and de-modulators. There have been big advances in the development of such components for the 1.55 μm window. However, there is increasing demand for components for the metro and local networks, those operating at 1.3 μm wavelengths. Photodiode sensitivity is one of the key issues in long-haul fiber optic communication systems. Owing to its internal gain which results from impact ionization, the avalanche photodiode (APD) is frequently the detector of choice over *p-i-n* photodetectors which have no gain, therefore, low sensitivity. The multiplication region of an APD plays a critical role in determining the overall gain and gain-bandwidth product. Both the multiplication noise and the gain-bandwidth product of APDs are determined by the ratio of the electron and hole impact ionization coefficients, which, for the most III-V compounds, approaches unity at high electric field intensities. In the case of only one type of carriers, for example electrons, are involved in the impact ionization process, for the holes, ionization coefficent is zero, leading to noise-free and wide bandwidth photodiode. APDs for wavelengths beyond 1.1μm use separate layers for light absorption (narrow band gap) and carrier multiplication (wide bandgap). Currently most optical communications systems use mainly the InGaAs/InP APDs. Control of the electric field at the interface between the layers is critical.

The current project is concerned with the development of novel photodetectors for the 1.3 μm window, with high sensitivity, fast response, low noise and suitable for the WDM applications, thus with the ability to receive optical information only at a specific wavelength while rejecting others. There are many semiconducting materials that can form the basis of such detectors and each is sensitive to a different wavelength. In this project we are going to use GaInNAs/GaAs structure and both photo absorbing and the internal gain regions are going to be in GaInNAs semiconductor. Dilute nitrides are very different from other semiconductor compounds in that adding small amounts of nitrogen changes its physical properties; lowers its band gap and makes it sensitive to light in the infrared such as 1.3 μm. They can be combined with GaAs technology such as GaAs substrates and GaAs based Bragg reflectors. Furthermore, electrons and holes created by the absorption of light are readily separated in dilute nitride quantum wells, holes are rapidly thermally activated out of the quantum wells as a result of very small valance band discontinuity and then swept away under the influence of the built-in electric field enabling electrons to be accelerated high kinetic energies without recombining with holes. This leads to electron controlled impact ionisation thus, noise-free impact ionisation (avalanche) and high sensitivity to optical intensity. The structure will contain multiple quantum wells (MQW) of GaInNAs/GaAs. MQW structure will be placed between n- and p-type doped layers and this *p-i-*n photodiode structure will be grown on a wavelength selective cavity, composed of GaAs/GaAlAs DBR layers. The structure will be fabricated in the shape of mesa structure with an aperture at the top. Devices will be grown at semiconductor growth centres at Tampere University of Technology and LAAS. Both are our partners within the EU COST Action MP0805) and have international reputation for the growth of III-V compound semiconductors, particularly very high quality dilute nitride/GaAs quantum well devices including, LEDs, Edge emitting (EELs) and vertical cavity lasers (VCSELs) and semiconductor optical amplifiers (SOAs). Devices will be fabricated at both Essex and once available at the IU fabrication facilities. Material characterization of the samples will be carried out using orthodox techniques such as Hall effect, Photoluminescence (PL), spectral photoconductivity (PC) (All in Istanbul İstanbul University). PL results will be used to determine bandgap of the samples and cavity resonance of the device. Spectral response will be determined with PC. I-V measurements will give information about reverse bias characteristics, breakdown voltage as a function of In and/or N composition and dark current. Speed, bandwidth and noise figure will be determined by transient photoconductivity at Essex University.

Project is going to be completed in 3 (three) years. And the stages of the project proposal contain that growth, design and characterization of (a) GaInNAs/GaAs MQW structure, which is both photon absorption and gain region, and (b) resonant cavity, (c) integration of cavity and detector structure, (d) characterization and delivering of the photodetector. At the end of project, it is aimed to develop of a novel photodetector for the 1.3μm with internal gain, fast response, high sensitivity. The project outcome has great potential to be published in respected SCI journals and patented. The main application area of the proposed device will be in optical communications, where there is a need for low cost, high sensitivity high speed photo-detectors operating at near infra-red wavelengths of 1.3 or 1.55 μm. The proposed device has internal amplification, thus high sensitivity; this coupled with low production cost to find applications in both metro and local area networks instead of using low sensitivity Si or InP based pin photodiodes without gain. High sensitivity, high speed photo-detectors impact a wide range of fields from astronomy to environmental protection (for example measurements of atmospheric pollutants and ozone) and defence. Another potential application may be biotechnology in, for example, ultra sensitive fluorescence for single molecule detection or detection of DNA micro arrays. Secure communication systems and quantum cryptography in which detection of single photons is the norm, may be another area of application. There is also a wide range of academic interest in the physical properties of dilute nitrides. Current proposal will provide ample information about the electronic and optoelectronic properties of these novel compounds. Since the project outcome is to develop an optoelectronic device, it will also contribute to increase knowledge and trained researchers in this field.