MATERIALS FOR LIGHT DETECTORS IN THE RESEARCH INSTITUTE FOR TECHNICAL PHYSICS*

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Abstract

Optoelectronics, especially the optical telecommunication needs high quality photodetectors with low noise and high sensitivity. Beyond 1 μm in the infrared region important for both selective spectroscopy and optical communication systems Si devices cannot be applied. As a possible solution of this problem new materials as ternary and quaternary antimonides were applied in heteroepitaxial form for developing new, wide band detectors.

Using GaAs based superlattices another possibility exists, therefore, quantum-well structures of GaAs/GaAlAs were developed for photodetector development.

Introduction

Light (photo) detectors convert optical signals into electrical currents for amplification and processing. When photons are absorbed in a semiconductor, those photons which have energies exceeding a threshold (bandgap energy) create electron-hole pairs. An applied external electric field of a *pn* junction separates spatially the free carriers, so they can move through an external circuit. Devices built according to this principle are e.g. pin photodiodes (PD-s) or avalanche photodiodes (APD). Si is a widely applied material for this operation at 850—900 nm because of its high quantum efficiency and fast response with low dark current. However, Si is transparent beyond 1 μm and for optical telecommunication and selective spectroscopy in the range of 1—10 μm there can be applied only Ge (between 1.2—1.6 μm) or compound semiconductors. Because of the band gap engineering of III—V ternary and quaternary materials these systems offer more freedom and flexibility for photodetector design than do Ge or binaries. Besides, the technology of producing multilayer heterosystems with sequentially or continuously changing bandgap is relatively easy and well developed for some heterosystems making semiconductor lasers.

Unfortunately, physical data are available only for a few materials of this kind. Lattice matching (phase diagram) carrier multiplication (impact

* Dedicated to Prof. J. Giber on the occasion of his 60th birthday.

ionization rate) and other physical and chemical data are necessary to develop new devices fulfilling the essential performance requirements as fast response, large bandwidth and good sensitivity (low noise and high quantum efficiency). During the last years at the Research Institute for Technical Physics experiments have been made for producing new materials and structures, to meet these requirements.

New materials for detector applications

In semiconductor detectors, particularly in heteroepitaxial PD or APD structures one has to obtain sufficient minority carrier life-time and diffusion lengths. Since interfacial defects (misfit networks) randomly reduce the mentioned parameters, it is very important to obtain good matching between semiconductor compounds used in the heterosystem. The preparation and growth of materials with a given bandgap (E_g) that is optimum for photodetector applications and the achievement of the control of a_0 lattice parameter matching the substrate are difficult. Applying ternaries ($A_x^{III}B_{1-x}^{III}C^V$ or $A^{III}B_y^V C_{1-y}^V$, where x refers to cationic, y to anionic components) the physical parameters (bandgap, refractive index n, a_0, etc.) are determined at a definite value by the substrate material. This limitation can be circumvented by quaternaries, which have four degrees of freedom (x, y, T and p), therefore, a wide range of compositions (as well as E_g) belongs to a definite a_0 value, and vice versa. This is the reason why our interest has turned to these materials.

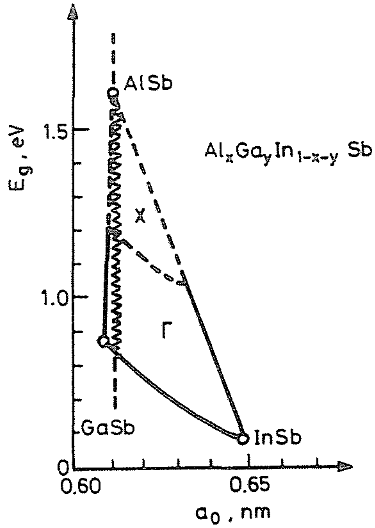

Fig. 1. a_0—E_g diagram in the AlGaInSb system

Among the possible compounds, only the symmetric GaInAsP has thoroughly been examined. No detailed study of $A^{III}B^{III}C^{III}D$ type speudo-ternaries have been performed. In these systems one of the sublattices, the cationic sublattice consists of three different atoms. According to our previous investigations, among the pseudo-ternaries the AlGaInSb (Zbitnew and Wooley, 1981 and Lendvay, 1982) proved to be the most promising photodetector material. The preparation of $Al_xGa_yIn_{1-x-y}Sb$ alloy was found to be difficult. Directional crystallization of melts result in a semiconductor boule with strong Al segregation along the crystallization direction. Homogeneous solid phases of this kind could be grown only by LPE techniques (Lendvay, Petrás and Gevorkian, 1985; Lendvay, Gevorkian, Petrás, Pozsgai, Görög and Tóth, 1985; Lendvay, Petrás and Gevorkian, 1985), using GaSb substrate material. Unfortunately, this semiconductor system cannot be lattice matched to any commonly used III—V binary, but GaSb has a very similar a_0 value presented in Fig. 1 making possible to grow heteroepotaxial systems with proper properties (AlSb, which can be lattice matched to a wide composition range of $Al_xGa_yIn_{1-x-x}Sb$ chemically unstable compound, so one cannot be applied, as a substrate). The lattice mismatch found in the GaSb/AlGaInSb system was in the order of 0.65% ($x=0.97$; $y=0.01$). The undoped phases similarly to the undoped GaSb and ternary antimonides show p-type conductivity ($p \sim 10^{17}$ cm^{-3}), but this conductivity can easily be transformed to n-type using Te as dopant. Applying this observation and p-GaSb substrate, p-GaSb/p-AlGaInSb/n-AlGaInSb heterodiode structures were grown (Lendvay, 1985) by LPE technique. Using the heteroepitaxial wafers photodiodes were prepared using AuGe metallization at the back side, and AuNi ring contacts on the front side. The photodiode has soft diode characteristics, and its photoresponse shown in Fig. 2 was surprisingly wide with a peak response at about 0.8—1.3 μm, covering both the spectral range of Si and Ge devices. The photoresponse curve was determined with front illumination and lock-in

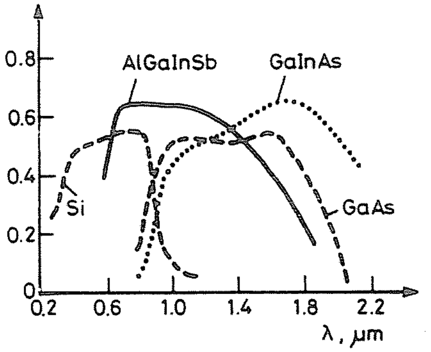

Fig. 2. Photoresponse of GaSb/AlGaInSb photodiode

technique using short circuit measurement. These preliminary results showed that improving the diode properties (semiconductor parameters as doping level, I—V characteristics, etc.) the system is very promising and has to be studied further in order to achieve optimum performance photodiodes. According to these results the AlGaInSb junction device functions in those spectral ranges where Si and Ge work and owing to this fact, it is suitable for replacing them in the first and second optical window unifying the receiver side in optical telecommunication.

Superlattice structures for optical detection

In these days superlattice (*SL*) applications extend to the photodetector field. High-gain avalanche photodetectors containing GaAs/GaAlAs *SL* regions can be constructed using a *p-i-n* structure, where the *SL* region is in the intrinsic region. When a hot electron enters in a GaAs quantum well, the ionization threshold decreases to a value of ΔE_{th}—ΔE_c, where ΔE_{th} is the ionization threshold energy and ΔE_c is the conduction band discontinuity in the *SL* region. (Similar conditions are valid for the valence band and to the holes). As the ionization rates depend exponentially on the thresholds, the ratio of electron and hole ionization rates (α and β) can be strongly enhanced, up to 7. Applying forward bias impact ionization, an almost noise-free multiplication process at the heterointerfaces occurs. It means that the *SL* region acts as a solid state photomultiplier with the steps in the energy bands corresponding to the dynodes of a traditional photomultiplier tube (Capasso, 1987).

Superlattices are grown usually by MBE or MOCVD techniques, but recently competitive LPE methods have also been developed in our Institute (Lendvay, Görög and Rakovics, 1985; Görög, Lendvay and Rakovics, 1987). Using a vertical, rotational LPE system different *SL* systems containing GaAs and GaAlAs layers with a periodicity of 20—100 nm and a layer number up to 100 were grown. Several structures consisting of *SL* active layers and GaAlAs confining layers, as well as structures where the *SL* region have been used to reduce the density of threading dislocations originating from the GaAs substrate, were applied. The LPE technology used has an impressive degree of control of compositional uniformity and layer thicknesses, although the GaAs/GaAlAs interfaces are not as sharp as in the case of MBE or MOCVD technologies. Among the possible applications of the aforementioned *SL* structures, the solid state photomultipliers are very attractive for photodetection. Utilizing the ability to produce the proper device structures with the desirable parameters photodetectors of this kind may be produced.

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