Optoelectronic Integrated Circuit Photoreceivers for Fiber-Optic Telecommunication

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In recent years, there has been tremendous interest in the optoelectronic integrated circuit (OEIC) receivers for high performance optical communication systems. The performance of a photoreceiver is mainly controlled by its front-end components - a photodetector and a preamplifier. A monolithically integrated photoreceiver has advantages of low parasitics, compact size and low cost. Commonly used photodetectors (PDS) are metal-semiconductor-metal (MSM) photodetector, PIN photodiode and avalanche photodiode. Among these, however, the first two are important for monolithic integration with amplifiers to form an integrated photoreceiver. State-of-the-art amplifiers used are based on the high electron mobility transistors (HEMTs) and heterojunction bipolar transistors (HBTs). Between MSM and PIN PDs, the former has an added advantage of high intrinsic bandwidth, ultra-low capacitance and easy planar integrability with HEMTs and HBTs.

Various structures and designs of PDs and transistors are used to get high performance photoreceivers. To obtain the best possible photoreceiver performance, it is very essential that the design should be an optimum. In the design of integrated photoreceivers, various device and technological parameters are involved. For optimization purposes, these parameters are to be tailored by exploiting the fabrication technology and device design. In fact, experimental researchers may use their knowledge and insights to tailor the parameters directly to produce devices with good performance. However, this becomes a difficult task in most cases because the devices' parameters are inter-dependent and hence cannot be controlled independently. This might mean several fabrication attempts to produce optimized structures and devices, but now the cost and time involved become a serious concern. However, both the cost and time can be significantly reduced and the task simplified if model equations and inter-relations among the parameters are known. Then an analytical and/or computational techniques can be used in an efficient manner to show how the device parameters can be tailored for structures with optimum performance. This approach can be a powerful guide to experimental researchers and device manufacturers in creating monolithically integrated photoreceivers for desired optimum performance.

To get a good design, it is always desirable that the devices are modelled as accurately as possible. For a photodetector, the two important parameters are the quantum efficiency (QE) and bandwidth (BW). In conventional surface-illuminated photodetectors, there is a trade-off between these two parameters - large thickness of the absorption layer means large transit-time limited bandwidth whereas small thickness reduces the quantum efficiency. Resonant cavity enhanced (RCE) structures with a very thin active layer is a possible solution structure. The thin layer gives rise to large BW, and the multiple passes of light in the absorption layer in the resonant cavity increases the quantum efficiency. A thin absorption region is placed in an asymmetric Fabry-Perot cavity. The top and bottom reflectors which can be fabricated by Distributed Bragg Reflectors (DBR) form the cavity.

Another way of improving the QE as well as transit-time limited BW is to use edge-coupled (EC) structures. Here, the requirements for high efficiency and high bandwidth are decoupled by illuminating the PD from the side of the absorption layer. Now, efficiency is a function of the length of the absorption layer, not its thickness. So, a thin absorption layer is good enough to get high efficiency at the same time increasing the transit-time limited bandwidth. In the resonant cavity structure, the construction of a DBR mirror is a complex process while the present one is a simpler one. EC structure uses the attributes of the waveguides. These are also suitable structures for coplanar optical interconnects.

The incorporation of Ge into the base of a silicon bipolar transistor can significantly increase the bipolar transistor performance. This makes it possible to consider the use of Si-Ge electronics to produce performance compatible with long-haul telecommunications requirements. It also provides access to a material with, meaningful absorption at much longer wavelengths than native Si. In particular it becomes possible to consider detector diodes with both increased absorption and longer wavelength sensitivity. Because of the 4% lattice mismatch between Si and Ge, the implementation of the receiver becomes more challenging at longer wavelength since the detector requires strained-layer epitaxial Ge_xSi_{1-x} films with higher Ge fraction.

In this paper we will make a thorough review of the previous research on the components and entire photoreceiver OEICs for telecommunications. To get the best performance, optimum design of the OEICs is based on the representative models of its components is required. We will describe our work on various models of photodetectors and amplifiers. We will discuss important effects such as interface trapping, diffusion and carrier velocity on the frequency response; and will consider a SPICE equivalent circuit of RCE PDs for the modelling. Simplified modeling of the active devices - HEMTs and HBTs - that are used in the design of amplifiers will be described. We will discuss our approach towards the optimum design of an integrated photoreceiver and show how optimization can lead to improved performance. Finally, as an example, the optimization study on RCE PIN PD and photoreceiver will be presented.