OPTOELECTRONIC TECHNOLOGY AND DEVICES IN EUROPE

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ABSTRACT

Over the past years exciting advances have been made in optoelectronic devices and circuits. The interaction of light with electronic systems is taking an ever increasing variety of forms. In this review we will focus primarily on optoelectronic devices for lightwave communication systems, although some related application areas will be touched. In the first section a rather general survey of advances in optoelectronic components will be given, with some emphasis on (but no limitation to) European achievements. In the second section a description will follow of European research programs related to optoelectronics, such as ESPRIT, RACE and EUREKA.

ADVANCES IN OPTOELECTRONIC TECHNOLOGY AND DEVICES

Introduction

A mere description of European developments in optoelectronics research would not very clearly set forward Europe's position in comparison with the rest of the world. Therefore it was chosen to present a description of worldwide achievements and to then refer to a number of European realizations.

Most attention in optoelectronics research of the last years has been given to components for wide-band long-distance communication using single-mode fibers, where people are aiming at datarates of several Gbit/s over hundreds of kilometers without repeater. However, other applications are being heard of at an increasing rate, such as optical links in a local distribution loop or at the subscriber's premises, links between computers, optical interconnect between subsystems or even between chips [1]. Local distribution loop experiments have been implemented in a number of European countries (e.g. Bigfon in Germany [2], Biarritz in France...). The wide variety of applications leads to quite different performance versus cost requirements, implying that a relatively large number of different optoelectronic components are needed. A description of a few important system specification parameters will be given first, so as to give a clearer view of what component to use for what purpose. Next we will turn our attention to some technological issues and finally a limited number of components will be discussed in some more detail.

System specification parameters

A first important system parameter is wavelength. In trunk networks the wavelength is largely determined by the fiber characteristics, having a minimum in dispersion and in attenuation at 1.3 and 1.55 μm respectively (silica fiber). Of the materials suitable for the fabrication of sources and detectors at these wavelengths the III-V quaternary compound semiconductors InGaAsP and InAlGaAs (lattice matched to an InP substrate) are most important. A strong research effort is therefore being put by most large European telecommunication companies into the development of these devices. In short data links with moderate bandwidth requirements, the fiber characteristics are relatively unimportant. Therefore a wavelength between .85 and .9 μm may be attractive (in spite of higher fiber loss) because it allows for the use of better developed and cheaper materials such as GaAs and AlGaAs. Devices with even shorter wavelengths are not very interesting for fiber communication but are being investigated for use in optical recording or printing applications. Here again materials lattice matched to GaAs, such as AlGaAs [19], InGaAsP, InAlGaP and even the II-VI's (e.g. ZnSe) are used. In these applications high output power in combination with a well-shaped output beam are of primary importance.

The wavelength list would not be complete without mentioning the efforts in the wavelength range beyond 1.55 μm. New fiber materials such as heavy metal fluoride glasses are being studied extensively because of their potentially ultra-low loss. Attenuation values of 0.01 dB/km are predicted at 2.55 μm but present state of the art fibers still show losses of several dB/km. At the same time new laser types for emission at these wavelengths, e.g. those based on Sb-containing III-V semiconductors, are being developed. Research in this last area is relatively limited in Europe.

Wavelength is one system specification parameter, source spectral purity is another one. Here again one has a choice from very broad to very narrow. If the fiber dispersion is low and the link relatively short, light emitting diodes (LED's), with typical linewidths of 50 nm, may be used. Bandwidth-distance products of between 5 and 10 Gbit.km/s have been demonstrated [3] by using LED's in combination with single-mode fibers. In long-distance or very high bitrate applications laser diodes need to be used. Depending on the requirements the presence of multiple longitudinal modes in the spectrum, spaced by typically 0.3 to 1. nm needs to be suppressed.

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In single longitudinal mode lasers it is desirable that the laser line is very stable over time. Especially in coherent optical communication systems the spectral purity and stability is of uttermost importance since the optical wave then functions as a carrier in a homodyne or heterodyne approach.

A third important parameter is component bandwidth at both the emitter and detector side. Optimized LED's do have a bandwidth of 1 GHz if they are of the spontaneous emission type and a little higher if they make use of stimulated emission. In the latter type the light extraction and fiber coupling efficiency is also much better than in the former [4]. For laser diodes bandwidths of between 10 and 20 GHz have been reported recently. High bandwidth needs to be accompanied with sufficient output power. A good measure is the maximum CW power at which the laser can operate. For conventional diodes at 1.3 μm for example output powers at room temperature of 150 mW have been demonstrated. An important problem is that the optical frequency in most laser types is dependent on drive current. This very property may be useful for frequency modulation in coherent communication systems. In conventional direct detection systems however, it leads to a highly undesirable chirp during pulsed operation, causing a limited system bandwidth due to fiber dispersion. One solution to this problem is to run a CW laser diode in a very pure and stable state and do the modulation externally. Such modulators have been realized in a planar waveguide or integrated optic approach by exploiting the electrooptic effect in $LiNbO_3$. The bandwidth of such modulators can also reach between 10 and 20 GHz by a proper electrode configuration. The implementation of such modulators on GaAs or InP is possible [5-7] but still suffers from high optical insertion loss and low bandwidth as a result of poor impedance matching.

At the receiver end equally high bandwidths are required. Clearly, the detector sensitivity is, for a given bit error rate, strongly dependent on the bit rate. There is a wide variety of detectors, each having their specific virtues [8,9]. PIN-diodes and APD-detectors are being developed in InGaAs for detection at 1.3 and 1.55 μm. At this moment the so-called SAM APD [23](with a separate absorption and multiplication zone) shows best performance with a sensitivity of -32dBm at 4 Gbit/s being reported. It is expected that novel APD structures will provide even better figures. Other detector structures such as the heterojunction phototransistor and the photoconductor are inferior in sensitivity but have other interesting properties such as high speed, fabrication compatibility [24-25] with other devices and high performance at longer wavelengths where p-n junctions stop to work properly.

Technology

All III-V semiconductor devices mentioned so far consist of a number of monocrystalline layers of different composition on top of each other. Therefore epitaxial growth technologies are most essential in their fabrication. Whereas liquid phase epitaxial growth (LPE) has long been the only reliable technique for a wide variety of III-V compounds, it is now being joined by two other most exciting epitaxy techniques, i.e. molecular beam epitaxy (MBE) and metalorganic vapour phase epitaxy (MOVPE). Both allow for the formation of very abrupt interfaces and very thin layers over relatively large areas, with good control of morphology and impurity content. Many of the recently developed optoelectronic devices exploit the benefits of either MOVPE or MBE. These epitaxial growth techniques are extensively studied and optimized in a large number of European laboratories and many of the manufacturers of epi-growth equipment are European.

Some specific devices

As mentioned before laser diodes operating in a stable single longitudinal mode are required in a number of applications. The distributed feedback (DFB) laser and the Cleaved-Coupled-Cavity (C^3) laser are two possible candidates. In the DFB-laser a periodically perturbed waveguide provides a wavelength selective feedback, resulting in single-frequency operation even under modulation. The C^3-laser consists of two closely spaced laser cavities that are coupled longitudinally. This also enhances the mode rejection. Research on C^3-lasers has been relatively limited in Europe (except perhaps from some theoretical investigations [10-11]), whereas there have been a number of reports on DFB-lasers. The first 1.55μm DFB-laser grown by a combination of LPE and MOVPE and the first all-MOVPE-grown 1.55μm laser are both developed in European laboratories [12-13]. The former has a linewidth of less than 10 MHz and a chirp during high speed modulation of less than 0.15 nm [14].

Another type of laser that has stimulated a lot of research is the quantum-well laser. In this device the active layer consists of one or a number of very thin layers with a thickness of typically 10 nm. Such lasers exhibit a wavelength tunability by geometrical parameters, an improved threshold current and temperature dependence and finally also an improved dynamic behaviour [15]. The first MOVPE-grown graded-index QW-laser was realized in Europe [16].

High speed operation of optoelectronic devices requires high speed electronic circuits such as laser drivers or detector signal preamplifiers. In order to decrease parasitic effects and to improve the noise performance and reliability in general, the integration of optoelectronic and electronic devices on a single substrate is being pursued. A major obstacle to the realization of such an optoelectronic integrated circuit (OEIC) is the high degree of diversity and incompatibility of the devices to be integrated. However, encouraging results have already been obtained both at 0.85 and at 1.3 μm in Japan and US. In most approaches the electronic circuitry is being implemented in the material required for the optoelectronic devices. A very attractive alternative is the recently developed 'GaAs on Si' technology, in which the (GaAs) optoelectronic devices are epitaxially grown on a Silicon wafer in which the electronic devices have already been realized. In Europe work on OEIC's has up to now been relatively limited, although important efforts are now underway.

In the previously described light modulators an electrical signal, normally at microwave frequencies, is controlling the optical transmission. A device in which the roles are reversed and which is of interest to the microwave society is the optoelectronic microwave switch. This device is used to modulate a microwave signal into short pulses (transmission path switching) or to modulate the oscillator itself (oscillator switching). These switches could for example find an application in high-resolution radar systems. In both cases short light pulses are used to change the properties of the transmission path or the oscillator. Microwave pulses down to the sub-nanosecond domain have been obtained in this way [17].

Many more optoelectronic devices deserve a discussion. These include among others optical amplifiers [20-21] and optical bistable elements of various forms [22]. Some detail on these devices will be given during the presentation.

EUROPEAN RESEARCH PROGRAMS

Both national and European community (EC) institutions promote research programs in optoelectronics. National programs are often to a certain degree characterized by a confidential nature, which implies that only limited information is available on them. The EC-programs are set up and coordinated by the Commission of the European Communities in Brussels. The program with the widest range is certainly ESPRIT, the European Strategic Programme for Research and Development in Information Technology. This program was launched in February 1984 and has a 10-year timetable with a first phase of 5 years. It concretized the Community's recognition of [18] :

'- the vital role of the Information Technology and Telecommunications sector to European industry as a whole'

'- the need to strengthen the Community's industrial base for greater international competitiveness'

The objectives of ESPRIT were formulated as

1. Promote European industrial cooperation in precompetitive R&D in Information Technology

2. Provide European IT industry with the basic technologies it needs in 5 to 10 years

3. Pave the way for standards

173 projects are running at the time of this writing. These involve about 1300 researchers in 484 organisations, comprising 263 industrial organisations, 104 universities and 81 research institutes. For the first phase 1.5 billion ECU's have been laid down, with a 50 % participation of the partners.

Optoelectronics is only a relatively small subarea in ESPRIT, with two main objectives, i.e. the realisation of integrated optoelectronic IC's and the realisation of wavelength multiplexing (WDM) systems. Five projects have been set up in the first phase. These include for example InP-based optoelectronic circuits and optical interconnect for VLSI and high bitrate IC's.

ESPRIT is now a mature program and the second phase is being prepared. It will, as far as optoelectronics concerns, quite strongly focus on device fabrication technology, in particular epitaxial growth processes (including GaAs on Si).

A second important program is RACE (R&D in Advanced Communication-technologies for Europe). As its name implies, RACE is more specifically oriented towards telecommunication. It forms a framework for cooperation with the objective of introducing a Community-wide Integrated Broadband Communication (IBC) Network by 1995. RACE has started in January 1986 with a definition phase of one year, in which a reference model for the IBC-network will be set up and in which key technologies that need a strong R&D effort will be defined. Projects within RACE are organized in much the same way as in ESPRIT. Optoelectronics forms an important part in RACE and a list of projects will be shown and discussed during the presentation.

EUREKA is another major European program. It was proposed by France in 1985. Countries that are not member of the European Community can also participate in this program. The funding for EUREKA is multinational and on a case to case basis, contrary to ESPRIT and RACE which are funded and coordinated supranationally.

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