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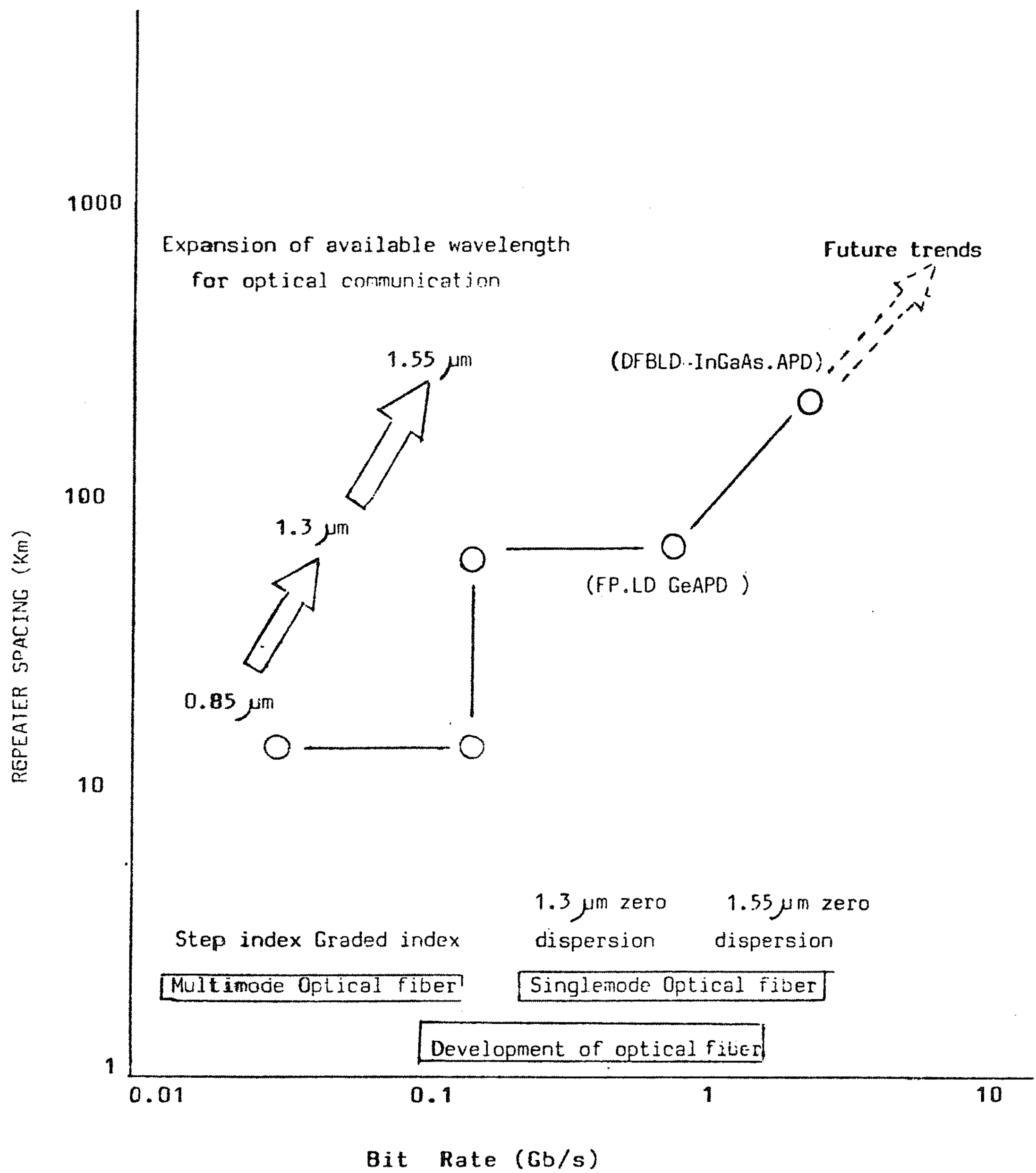

Fig 1. DEVELOPMENT TREND OF LIGHTWAVE SYSTEMS

performance single – mode fiber systems operating 1300 nm are either InGaAs pin diodes or Germanium APD. Pin detectors are equally suitable for operation in the 1550 nm window but Germanium APD's are not used at that wavelength due to low quantum efficiency and high dark current. New APD designs based on III – V material systems giving high perfor– mance at 1550 nm will, however, be commercially available in the near future [28, 29, 30].

Intensity modulation and direct detection (IM/D D) is the basic principle of all present day fiber optic transmission systems. A laser or LED source is intensity modulated, and a photocurrent is generated at the detector which is proportional to the received power. The detector is essentially a power detector basic principles can be illustrated through considering the simplest form of semiconductor detector, the pin diode.

C. Current Status:

For 0.85 μm wabelength operation which many systems are already installed and rarely used today, Si type detectors still offer the best solution; both pin diods and APD's.

Commereially available Si pin diodes can typically achieve quantum officencies of 75% operating at 10 Volts inverse bias a bandwidth of approximately 500 MHZ is available. The Si APD is an excellent device but requires 200 – 300 Volts bias to achieve gain around 100 with 500 MHz bandwidth. The APD can offer very significant receiver sensitivity improvement over the pin diode [31].

Germanium detectors, though capable of operation out to 1.55 μm, have predominantly been used at a wavelength of 1.3 m. The Ge APD has found the greatest application because at this wavelength it is at present the only commereially available APD. Opera– ting voltages for Ge APD's are lower than for Si devices, being typically 30 – 40 Volt, and bandwidth Up to 1 GHz are available from commercial devios(32). At long wavelength (1.3 to 1.55μ m) theGaInAspin pioed is the detector favoured for high data rate operation. TheGaInAsis the basic of commercially available receivers for data up to 505 Mbit/s and the prototypes suitable for operation at 2.5 Gbit/sec are be coming available [32, 34, 35].

V. Current Status of Optical Fiber Systems:

Current development trend of lightwave system can be found in large number of references [36 – 44] This trend can be summarized as figuer.1.

As this figure shows the first stage was at 0.85 μm wavelength using multimode fiber, which has been greatly inatalled in past. Second stage use 1.3 μm wavelength with greater repeater spacing which is using single – mode fiber with zero chromatic dispersion and approporiate sources and detectors, 2nd stage is mainly the current developed systems. But third stage which is going to use 1.55 μm, Although the fiber loss has its minimum valuse but the chromatic dispersion is not yet zero. The next few years is going to shift the zero dispersion wavelength to 1.55 μm Therefore will increase the repeater spacing distance & available transmission bandwidth.

The future trend will be mainly on coherent system, which is not discussed here.

$$\Lambda = \frac{\lambda}{2} M$$

where Λ is the period of the grating, λ is the optical wavelength and M(integes) is the "Order" of the grating[19].

For local loop and other short haul applications LED may be used with single – mode fiber due to cost and reliability advantages over laser diods[6,19]. Their output power is less temperature dependent and they don't normally need external control circuits. LED are currently being investigated for short haul, low, medium and high data rate links to meet the evolutionary demands for the emerging broadband integrated services digital network.

Two basic device structures are available for monomode LED's. these are the surface emitting and edge emitting geometry. In general higher optical powers have been achieved with the latter whereas the former offers simpler processing and packaging, with hence potentially lower cost, and a lower temperature coefficient [21],[22].

Modulation rates are somewhat dependant on device structure and drive components. Commerical devices are now readily available for data rates up to 200 Mbit/Sec, but many experiments have been performed with edge LED's at 565 Mbit/Sec and even 1.2 Gbit/Sec[23].

Surface emitting LED's have also been proposed and demonstrated for use in single– mode fiber systems [24],[25]. The advantage of the surface geomety is in simple banding, non critical fiber placement and planar processing. The main disadvantage is the relatively low power, with 1.5 μm being reported for a device suitable for 565 Mbit/Sec operation [25] & the wider spectral width, although the lower temperature coefficient partially compensates for these disadvantages in practical systems.

D. Current Status:

At this time, commericially available Fabry – perot laser for operation at 1300 nm provide typically a peak output power into single – mode fiber of 1 mw (0dB m) on systems using long section length speed is limited to 565 Mbit /Sec[26].

Single – mode laser of DFB design for operation at 1550 & 1300 nm have become available. Their power is currently a few dB's lower than that FP lasers. These devices are required for long – haul systems at data rates above 565 Mbit/Sec or for long-haul lower data rate systems operating in the 1550 nm window on fiber to Recommendation G.652[9].

For medium and short haul systems, at data rate up to 140 Mbit/Sec (junction systems), Lasers with lower output power can now be obtained at substantially reduced cost. They are normally used without a cooler and with reduced complexity control circuits. LED diods for single – mode fibers are a commerically attractive alternative at the shorter end of this distance range [27].

V. Detectors:

A. General:

Optical detectors are required to demodulate the received optical carrier wave and to recover the electrical information singal. Amlification and filtering of the electrical signal is then carried out in and associated receiver circuit. The electrical output signal from the receiver must have a sufficiently high signal to noise ratio to permit regeneration of the information signal at a bit error rate less than the design limit (typrically 10^{-10}). The minimum received power required to achieve this signal to noise ratio is termed the receiver sensitivity is expressed in dBm.

B. Basic Principles:

Devices commonly used in modern high

to a few hundred MHz. They are used where line atten uation, and dispersion are not critical such as in low and medium data rate systems over moderate distances, they are simpler in design and construction than lasers and are, therefore generally cheaper [5 – 7].

Eearly optical fiber transmission systems operated at wavelengths around 0.8 – .9 μ m over multi – mode fiber. These systems were based on LED & laser source fabricated in the GaAs/GaAlAs material systems. For systems operating of wavelength GaInAsP/InP have been developed [15].

Many publications exist dealing with optical devices and covering all aspects of device technology, operating principles and system requirements. CCITT publication "Optical Fibers for Telecommunications" gives an introduction to the subject [16].

B. Basic Principles of Emission.

The basic mechanism which applies to light – emitting diode is spontaneous emssion. When a conduction band electron fall into a valence band hols, energy equal to the fundamental gap is liberated in the form of light, i.e. phone emission. The recom–bination process may occur spontaneously at a rate which is proportional to the density of electrons and holes. The emission wavelength λ may be tuned by choosing a semiconductor with energy gap according to the relation [17].

$$E_g \lambda = 1.24 \text{ ev.} \mu\text{m}$$

For example in GaAs of energy gap E_g = 1.42 ev, the emission wavelength is around 0.9 μ m.

The fundamental process in laser (light ampli–fication by stimulated of radiation) is stimulated emission. When energy states close to the conduction and valence band edges are fully occupied with electron & holes (population inversion) an incident photon may stimulate a recombination Process resul–ting in the emission of an identical photon. Therefore the active region acts as an amplifier, which can be tuned into an oscillator by providing a feedback. In a semiconductor laser the feedback is provided by reflection from the facets since the two cleaved facets form a resonant (Fabry – Perot) cavity. Lasing takes place on a cavity mode where the phase change on a round trip is a multiple of 2π i.e.[18].

$$- \qquad \frac{2\,nL}{\lambda} = \text{integer}$$

Where n & L are the refractive index and cavity length. Since the sepectral width of the gain curve is very wide compared to the sparation between the cavity modes, a semiconductor laser usually operates in several longitudinal modes. Such multi – mode laser are usually referred to as "Fabry – perot" lasers.

B-

C. External Cavity Laser And LED for single – Mode Appli–cations:

One way to improving the spectral characteristics of semiconducter laser is the use of external cavities containing wavelength selective elements. Such devices however, tend to require a high level of mechanical stability.

Structures with built – in wavelength selectivity such as DFB (distributed feedback) laser seem much more promising. DFB laser contain a periodic grating on the boundary between two layers in the laser structure. This corresponds to a periodic variation in the refractive index. because of refractive index variation. The condition that these small reflections interfere constructively can be written as propagate, can be determined.

Attenuation is another characteristics of fiber. At a distance of L Kilometer from the transmitter, the power level is $P_T \exp(-\alpha L)$ where P_T is the power launched by the transmitter into the fiber and α is the attenuation constant. It is to be noted that above relation applies for single – mode fiber, is also used for multi – mode ones even if in such a case is weighted average over the propagating modes so that its value actually changes along the fiber.

For single – mode fiber it is important to have a reasonable spot – size for the fundamental mode in order to simplify connecting and splicing. Attempts have been made to characterize this distribution with a single parameter called the mode field diameter. This is usually done by r.m.s. width of the field distribution in the fiber (13).

The bandwidth of a single – mode fiber is determined by its structural and physical parameters as well as its material properties, mainly through chromatic dispersion. Chromatic dispersion, which for normal fibers is zero near 1300 nm, is caused by propagation delay differences among different spectral components of the source signal, so that the pulse broadening can be expressed by $L.\,\sigma_{\lambda}[\frac{dt}{d\lambda}]_{\lambda=\lambda_s}$ where L is the fiber length, the group delay per unit length, λ_s the central wavelength and λ_s, the r.m.s. width of the source [14].

D. Current Status

Multi – mode fiber which had major use in past few years, are going to have less application, the single – mode fiber technology has exploded and it is still in evolution. In fact new fiber design and systems phylosophies are arising and they are calling for new characterization techniques. Nevertheless the situation in the characterization of single – mode fibers optimized at 1300 nm is being consolidated from the point of view both of the standadization and of the instrumentation availability.

Around 1550 nm which the fiber attenuation is minimum the chromatic dispersion is present therefore dispersion shifted fiber is going to be developed in next few years [15].

III. Optical Sources

A.General:

The primary function of an optical source is to generate the optical carrier wave needed for the transmission of the electrical information signals over the optical fiber, it must therefore emit light at a wavelength matched to one of the low – loss transmission windows of the optical fiber.

In Systems operating on single–mode fiber based on CCITT Recommendation G. 652[9], transmission window is in the 1300 nm region and typically up to 60 nm wide. An even lower loss window exists in the 1550 nm region on suitable fiber systems.[5–7].

In systems requiring long repeater sections and high data rate operation, the output power of the optical source should be high. The emission spectrum should be narrow in order to minimize chromatic dispersion effect [7].

Semi – conductor laser diods meet these requirements. In these devices, the light generated by the electro – optic converision process is selectively amplified (stimulated emission) in a resonant cavity thus giving high output power over a narrow wavelength range, together with a well confined light beam.

Ligth emitting diodes (LED's), on the other hand use spontaneous emission without amplification.

Ligth emitting diodes (LED's), on the other hand use spontaneous emission without amplification. They produce lower output power and have a wider emission spectrum. Their modulation rate is limited

ted very high bandwidth and long link without epeater. These achievements included the development of extremely low – loss (0.2) dB/Km) doped ilica fibers and the demonstration of zero dispersion peration of these fibers. Research and development hifted from 850 nm spectral region to the 1300 – 500 nm region where optimized optical data link erformance may be achieved the use of single mode ibers in this spectral region has minimum loss. In ddition to having a low loss and a large bandwidth ptical fibers are resistant to crosstalk and electromagnetic interference and are based on abundant raw naterials, The ideal single – mode fiber, for long listance transmission of digital information has a ircularly symmetric structure with concentric core and cladding regions. Ideally it should carry a single – node (HE_{11}) which suffers negligible dispersion and oss over a wavelength range compatible with available optical transmitters and receivers. [6 – 4].

B. Standardization And Operating Wavelength

CCITT have issued Recommendation G. 651 dealing with multi – mode fibers and G. 652 dealing with single – mode fibers. The multi – mode have silica or composition, graded index and may be used with a source having a wavelength in the region of 850 nm or one having a wavelength in the region of 1300 nm or alternatively may be used in both wavelength regions simultaneously. The single – mode fibers have to be optimized for use at wavelength regions of around 1300 nm and may be used at regions of around 1550 nm [8,9].

Since single – mode fibers have a low– loss at 1300 nm (0.4 dB/Km) and in this region they also show zero chromatic dispersion, there is the possibility of high speed transimission over long links with little degradation of the propagating pulses [10].

The loss in the 1550 nm window is even lower (0.2 dB/Km), but narrow spectrum sources must be used to overcome the problems which could arise from the chromatic dispersion of about 20 PS/nm. Km, which could otherwise limit the available bandwidth [11].

A different approach consists in shifting toward 1550 nm or flattening between 1300 and 1550 nm the low dispersion region, by suitably modifying the refractive index of the fiber.

C. Characteristics of Fibers

For single – mode fibers it was decided not to standardize the core geometrical characteristics but rather its transmission ones. Instead of the core diameter, it is the mode fiels diameter which has been standardized in recommendation G. 652 [9].

Concerning the cladding diameter it was decided to confirm the value already selected for multi – mode fiber.

In single – mode fiber, the shape of refractive index is not important – from the transmission point of view, which it plays a major role in the design of dispersion shifted and dispersion flattened fibers.

The simplest single – mode fiber refractive index profile involves a step change in index accross the core to confine the optical power. A step – index fiber operates in the single – mode regine of the V number, or "normalized frequency", satisfies the condition [12].

$$V = Ka \sqrt{n_0^2 - n_1^2} < 2.405$$

Where 2.405 corresponds to the first zero of the 0th order Bessel funation, a, is the core radius, $k=2n/\lambda$ is the wavenumber (λ is the free – space wavelength) n_0 and n_1 are the refractive index core and cladding respectively. From the above equation the cut – off wavelength, above which higher order modes can not percent of its fundamental frequency.

Experimental unguided optical communication systems were developed shortly after the discovery of laser using a light beam travelling through the atmos– pher condition caused an interest in optical systems which guide the light [1].

In fact at a early stage of studies, glass fibers were not considered as suitable transmission medium for optical systems due to high values of attenuation (several thousand dB/ km). There was tremendous effort to reduce attenuation by purification of the materials. This resulted in improved conventional glass refining process and allowed fibers with lower attenuation to be manufatured [2].

In 1970 the production of several hundred meteres of single mode fiber having an attenuation of less than 20 dB/km was achieved and, in 1972, it was possible to obtain of less than 4 dB/km. The exploitation of wavelengths in the regions between 1100 – 1600 nm, where material intrinsic loss is lower, desired a shift in optical fiber source and detector technology in order to provide operation at longer wavelengths. At these longer wavelengths. especially around 1550 nm, fibers with losses as low as 0.2 dB/Km have been reported [3].

Low attenuation and low dispersion in optical fiber have created new possibilities for long distance, high bit rate transmission on optical fibeıs. Research was also stimulated for the development of sources suitable for the new wavelength region, laser diodes and LED's are nowadays commericially available with suitable performance in terms of emitted power wavelength spectrum and projected life.

The results obtained in the field of optical sources and of transmission media have also stimulated studies for the development of corresponding optical detectors, The first generation had wavelength 800 and 900 nm. However taking into account the considerable advantages that may be gained from second and third window operation (i. e. 1300 ánd 1550 nm), by having lower attenuation and zero dispersion to stablish longer links with higher capa– cities.

C. Single mode versus Multimode Systems

Optical communication fiber systems have already been used in telecommumcation network. The initial work was with single – mode fiber but very quickly shifted toward multi – mode graded – index techno- logy because of the lack of suitable technology to handle less than 10 μm single – mode fiber cores [4].

Single – mode fiber are a superior transmission system as far as available bandwidth is concerned so that the research progress went toward single – mode fiber systems. Around 1980 it was immediately evident that the adoption of single mode fiber system in the trunk network offered a significant saving in expenditure due to the immediate advantages of larger regeneration section length and higher bit – rates [5].

Moreover single – mode technology offers the possibility of upgrading the links in case of future demands of laser capacities. However multi – mode optical fiber system are continuing to have a less demanding applications but single – mode technology has exploded and it is still in evolution for high capa- city and long distance use. Therefore in this paper we will discuss the various fibers, sources and detectors for single – mode optical fiber systems. Also current status of overall system will be discussed.

II. Optical Fiber Cables

A. Ceneral:

By the late 1970's rapid progress has occurred in optical communication technology which has permi–

REVIEW

Current Trends in Optical Fiber Communications

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ABSTRACT

Current trends in optical fiber commun– ication systems including fibers, detectors and sources are investigated.

I. Introduction

A. General:

During the past years a new technology has become increasingly used in the fields of communi– cation transmission via optical cables. In contrast to copper cable technology, here, signals are transmitted optically with the aid of optical waveguides – optical fibers. This development was suppcrted by the avai– lability of suitable semiconductor components such as lasers, light emitting diodes and photodiods. At hte same time, digital transmission systems already in operation were upgraded to meet the demands of optical fiber technology.

The exploitation of optical fiber systems in the field has progressed with in both national and inter– national telecommunication network, as well as in local data communication. The trend will undubtely continue and the future installation will ensure a wide application of optical transmission systems in the longdistance, and local network. Therefore, to help in system selection, it will be very usefull to consider the present trends of optical fiber communication systems, especially three main components of system which are: fibers, sources and detectors. Future trends will not be discussed here in detail.

B. Historical Development of Optical Fiber Systems

The modern idea of optical communication originated with conventional sources of light: laser radiation is highly monochromatic and coherent, and very intense. It was thus a natural step to think of laser potential for telecommunications. Initially the principal motivation was the enormous bandwidth available, if the laser light is modulated even at a few