InP layer is found not to be constant. The data can be understood in terms of four different generation rates. The highest rate was observed in the InP-buffer layer far away from the InGaAs heterointerface. We conclude that this is due to a high trap concentration or high emission rates of the traps in this layer. However, the traps causing the dark current in each layer are different between the layers. The effective lifetime found for InGaAs of $\tau_{eff} = 590$ ns is very high for such a type of diode compared to other values.[4] To lower the dark current of these diodes it is not sufficient to use a lower reverse bias. Rather, it is necessary to investigate the causes for the formation of layers with different generation rates during the epitaxial process, especially of the layer InP II. Our results suggest it should be possible to lower the dark current by more than 1 nA, if this layer is not present. However, to lower the dark current further, a reduction of all dark current components is necessary. In addition, it has been found possible to measure the effective lifetime of the carriers resolved as a function of depth with the previously described methods allowing more information about the vertical homogeneity of the diode layers.

Table 1 SUMMARY OF LAYER PARAMETERS OF DIODE

Layer	InGaAs	InP I	InP II	InP III
$U(x)$ ($cm^{-3}s^{-1}$)	9.2×10^{17}	9.2×10^{17}	2.7×10^{18}	3.4×10^{17}
τ_{eff} (ns)	590	1.3×10^{-2}	4.4×10^{-3}	3.5×10^{-2}
ΔE (eV)	0·48	0·55	0·55	0·60

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CONCATENATED SOLITON FIBRE LINK

Indexing term: Optical communication

An easy and practical 'soliton fibre' link by concatenating uniform fibre sections is proposed. An ultrahigh bit rate loss-limited fibre communication system can be achieved.

Introduction: An optical soliton can maintain its pulse shape in a lossless fibre. Owing to the fibre loss, the intensity of the pulse decreases with the distance and the soliton disperses. By tailoring the fibre core, we can have a kind of 'soliton fibre' whose dispersion decreases exponentially with the distance so that the broadening effect of the soliton due to the fibre loss can be compensated for completely.[1] This method needs precise control of the varying fibre core diameter and is not practical in production. A real fibre communication system is usually linked by multiple fibre sections. To approximate the soliton fibre, we use the concatenated fibre sections with discrete uniform dispersions. We propose a scheme such that the first order dispersion of each fibre section satisfies the following relation:

$$K''_n = K''(0) \exp[-\alpha(n - 1 + r)L] \quad (1)$$

where K''_n is the 2nd order derivative of the propagation constant for the nth fibre section, $K''(0)$ is the 2nd order derivative of the propagation constant at the input end of the soliton fibre, L is the length of each fibre section, α is the fibre loss with a value of 0·2 dB/km, and r is the adjustable distance parameter. Near the zero-dispersion wavelength (λz), K'' varies almost linearly with the wavelength separation ($\Delta\lambda$) from λz. Notice here that λz varies with distance and that the optical carrier wavelength is fixed. As shown in Fig. 1, the solid line represents the $\Delta\lambda$ as a function of the propagation distance for the soliton fibre and the dashed line is for the concatenated fibre sections with 8 km section length. Here, λz of the soliton fibre at the input end is assumed to be 10 nm less than the optical carrier wavelength. To account for the influences of the higher-order dispersion on the pulse evolution, we use the split-step Fourier method to solve the modified nonlinear Schrödinger equation[2]

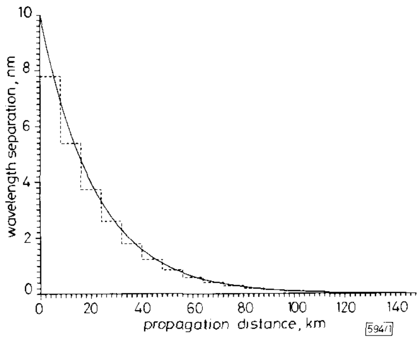

Fig. 1 *Wavelength separation of λzs between optical carrier and fibre as function of propagation distance for perfect soliton fibre and fibre link concatenated by fibre sections 8 km long*

——— perfect soliton fibre
– – – – fibre link concatenated by fibre sections

$$j\, dq/d\xi + d^2q/d\tau^2 + |q|^2 q = -j\Gamma q + j\beta\, d^3q/d\tau^3 \quad (2)$$

where q, ξ, τ and Γ are normalised electric-field amplitude, propagation distance, time, and fibre loss, respectively. The higher-order dispersion factor β is equal to $k'''/(6T|k''|)$, where k''' is the 3rd derivative of the propagation constant, and T is the time scale factor and is equal to the input pulse-width (FWHM) divided by 1·763. The common dispersion curve of fused silica[3] is adopted and is shifted parallelly to $\lambda z = 1.55\,\mu$m. To avoid the interaction of solitons, ten times pulse-width are adopted as the slot for a bit and the central seven pulse-widths are used as the detection window to measure the root mean square pulse width. One thousand photons per bit are assumed as the detection limit.

Results and discussion: The initial input pulse width is assumed to be 3·85 ps and the 0·1 dB splicing loss for two fibre sections is included. We choose the proper distance parameters for various section lengths to obtain the loss-limited output pulse with the same pulse width as that of the input pulse. At the input end of each fibre section, the decayed peak power of the soliton from the previous section is amplified due to dispersion compensation. The enhanced nonlinear effect overcomes the dispersion effect and narrows the pulse initially. Without the splicing loss effect, the required propagation distance for the development of pulse narrowing varies inversely with the nonlinear effect, so the distance parameters have larger values for shorter fibre sections as shown by the dashed line in Fig. 2. Taking account of the splicing loss effect, we need a stronger dispersion compensation to amplify the

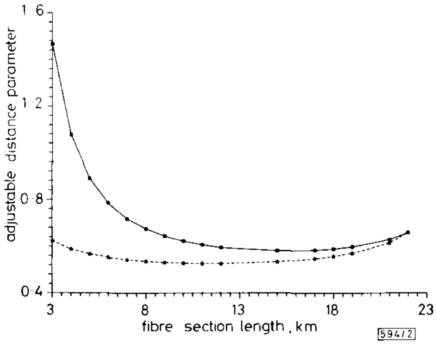

Fig. 2 *Adjustable distance parameter of dispersion compensation as function of fibre section length for cases with and without inclusion of splicing loss*

——— splicing loss included
- - - - splicing loss not included

delayed peak power of the soliton as shown by the solid line in Fig. 2. A minimum value of the distance parameter is found near the 15 km section length. For longer fibre sections, the dispersive tails from the pulse narrowing become significant, and we need a larger distance parameter to compensate for the dispersion. A maximum length for fibre sections should exist due to the pulse splitting effect of the higher order soliton under the influence of fibre loss, and the initial pulse-width cannot be recovered. Fig. 3 shows the pulse-width variation as a function of the propagation distance for various section

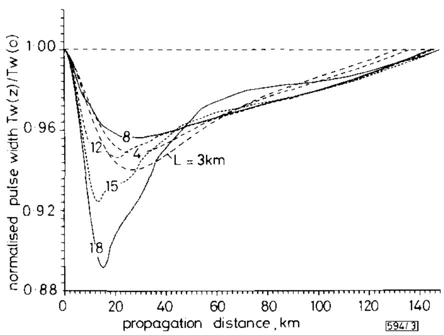

Fig. 3 *Pulse width normalised to input pulse-width as function of propagation distance for various fibre section lengths*

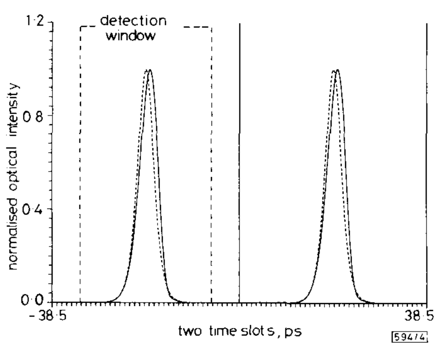

Fig. 4 *Initial pulse profile and output pulse profile at Z = 144 km for fibre section length of 8 km*

Two neighbouring bits are shown here, and output pulse is rescaled for comparison
——— initial pulse profile
- - - - output pulse profile

lengths. Without the splicing loss effect, the longer fibre sections should have a stronger pulse narrowing. Owing to the splicing loss effect, the ratio of 0·1 dB splicing loss relative to fibre loss of the fibre section for the shorter fibre section is large, the heavier dispersion compensation is necessary and the stronger pulse narrowing is developed. For the section length above 8 km, the splicing loss effect is not too significant. Fig. 4 shows the temporal profile of normalised output pulses (solid line) for a 144 km long fibre link concatenated from eighteen 8 km fibre sections. In spite of a small shift of the pulse peak, which is due to the higher-order dispersion, the output pulse is well suited for detection. From the above example, the bit rate distance product is up to 3740 Gbit/s km.

Conclusions: A practical 'soliton fibre' is approximated by a concatenated fibre link, and an ultra-high bit rate loss-limited fibre communication system can be achieved. The fibre sections required can be chosen from the conventional production.

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MICROLENS ARRAYS FOR INTERCONNECTION OF SINGLEMODE FIBRE ARRAYS

Indexing terms: Optical fibres, Lenses

The efficient coupling of light between arrays of singlemode optical fibres has been demonstrated using arrays of refractive microlenses. The arrays are highly uniform in both spacing and the optical properties of the individual lenses.[1] These lenses have little chromatic aberration, and concurrent operation at wavelengths of 1308 nm and 1540 nm has been demonstrated.

Introduction: The advantages of the small diameter of optical fibre (typically 125 μm) can only be fully exploited if connection between fibres and other components in the system can be performed in parallel. Linear arrays of sources, fibres and detectors are already available, and there is, therefore, a need for compatible arrays of microlenses. To achieve efficient coupling, these lenses should be of uniformly high quality, their numerical aperture should be somewhat greater than that of the fibres, and they should introduce negligible aberration into the transmitted wavefront.[2] Furthermore, as fibres may be expected to transmit light simultaneously across the 1200–1600 nm wavelength range, it is important that the lenses should exhibit very low levels of chromatic aberration. The purpose of this Letter is to describe the results of preliminary experiments in which arrays of microlenses produced by the melting of photoresist were used to couple light of various wavelengths between singlemode optical fibres.

Manufacture of microlens arrays: The lenses were made by melting arrays of small cylinders of photoresist formed on a glass substrate. The cylinders were generated using conventional photolithographic techniques by exposing a layer of