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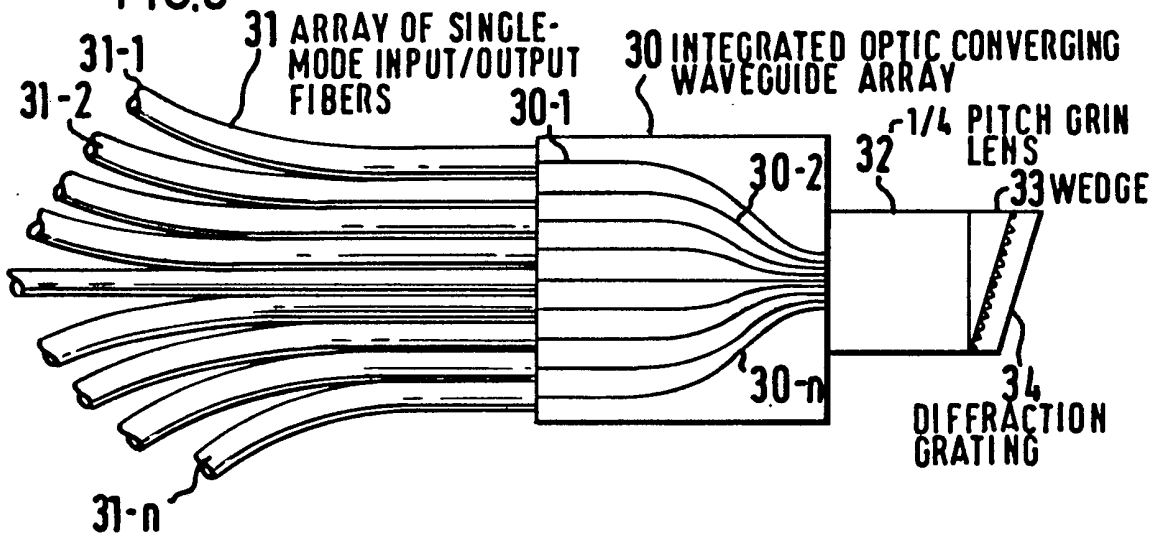
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(54) Optical multiplexer/demultiplexer

(57) A diffraction grating wavelength division multiplexer/demultiplexer comprises a reflection-type diffraction grating (34), a lens (32), and a linear array of single mode optical fibres (31). An integrated optical, converging waveguide array (30) is inserted between the single mode fibres (31) and the lens (32). This achieves close packing of the channels and hence more efficient filling of the available bandwidth than is otherwise possible with single mode fibres owing to their small core-to-cladding ratio.

FIG.3



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FIG.1
(PRIOR ART)

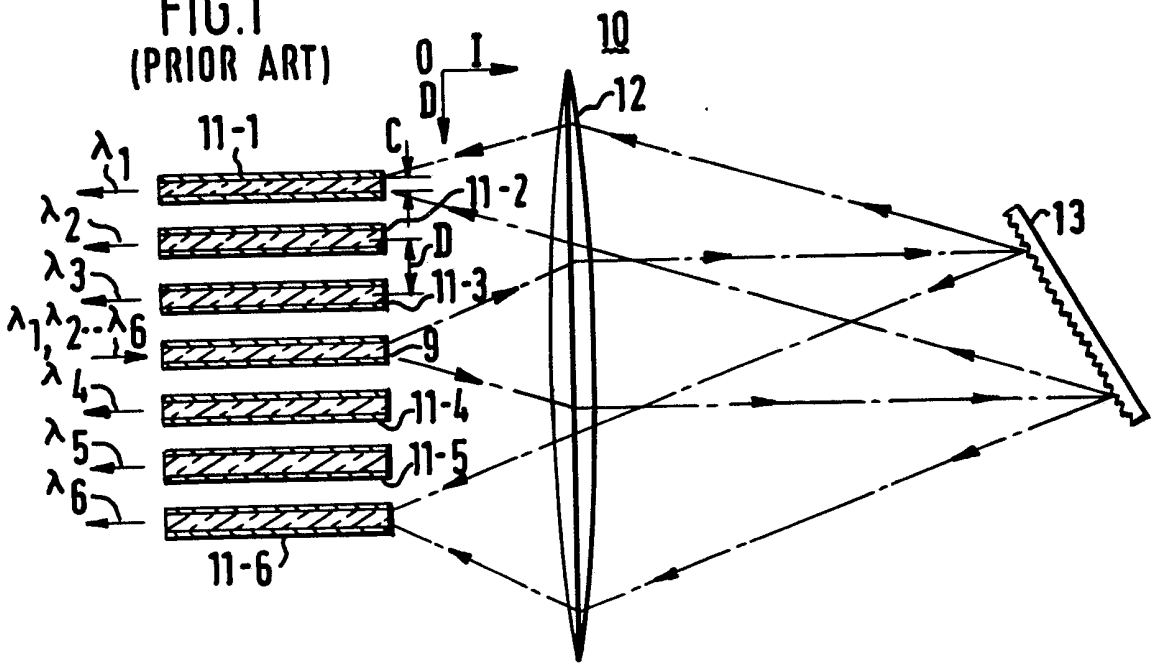


FIG.2

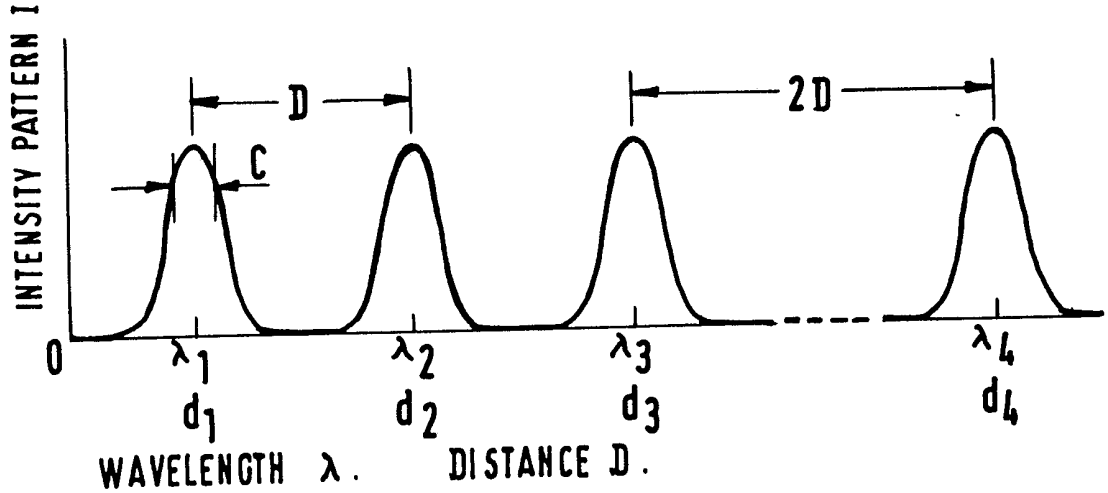


FIG.3

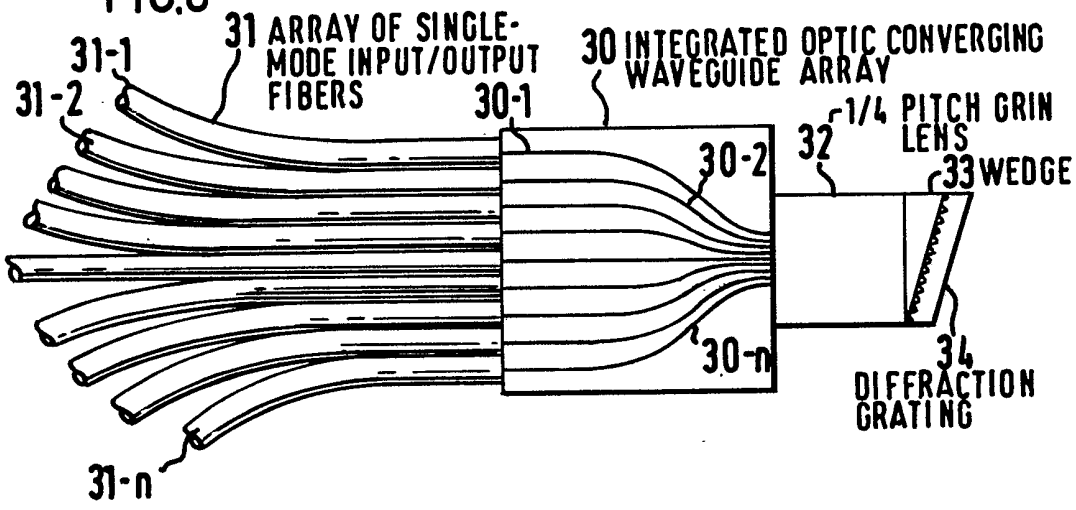


FIG. 4

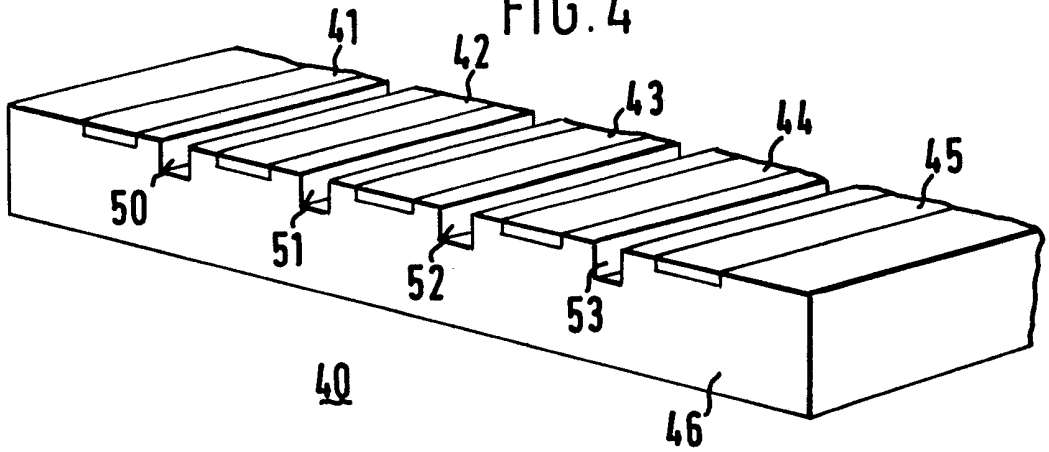
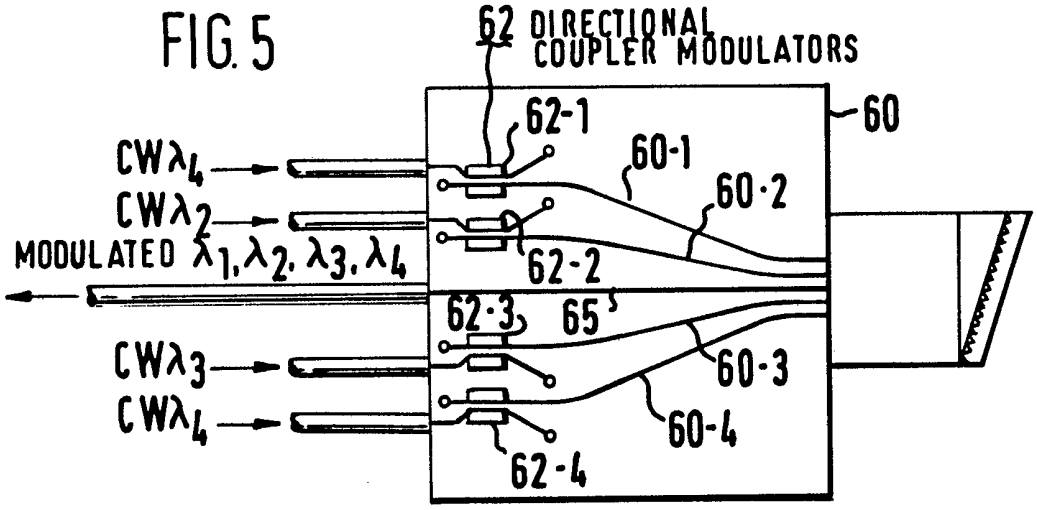


FIG. 5



SPECIFICATION

Optical multiplexer/demultiplexer

This invention relates to optical multiplexers and demultiplexers.

As the low-loss wavelength region of optical fibres has expanded, techniques for utilizing this increased bandwidth by simultaneously transmitting several signals of different wavelengths along each fibre are being investigated. One such technique utilizes angularly dispersive devices such as gratings. (See, for example, "Optical Devices for Wavelength Multiplexing and Demultiplexing" by W.J. Tomlinson; also see "High-capacity Wavelength Demutiplexer with a Large Diameter GRIN Rod Lens" by B.D. Metcalf et al., published in the March 1, 1982 issue of *Applied Optics*, Vol. 21, No. 5, pp. 794–796; and "20-Channel Micro-Optic Grating Demultiplexer for 1.1–1.6 μm Band Using a Small Focusing Parameter Graded-Index Rod Lens" by M. Seki et al., published in the March 18, 1982 issue of *Electronics Letters*, Vol. 18, No. 6, pp. 257–258).

Such devices typically comprise a fibre array, a lens and a grating. When used as a demultiplexer, a plurality of signals at different wavelengths enter the device along an input fibre, are collimated by the lens and directed onto the grating where they are dispersed as a function of wavelength. Each of the diffracted beams is then focused onto a different one of the remaining fibres. In this way the signals are spatially separated for subsequent independent processing. When operated in the reverse fashion, signals in each of the fibres can be multiplexed for simultaneous transmission along a common fibre.

Such devices are well suited for demultiplexing multimode and single mode signals. As noted by Tomlinson, however, they are not very efficient when used to multiplex single mode signals. The problem arises from the fact that in a single mode fibre the core diameter is small compared to the outside diameter of the cladding. Consequently, close packing of the channels cannot be obtained, resulting in inefficient use of the available bandwidth.

According to the present invention there is provided an optical multiplexer or demultiplexer comprising: a linear array of single mode optical input/output fibres, a diffraction grating for selectively coupling optical wave energy between one of the fibres and the others of the fibres, a lens for focusing said coupled energy and an integrated, converging waveguide array interposed between the fibres and the lens.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:–

Figure 1 shows a known reflection-type, diffraction grating multiplexer/demultiplexer;

Figure 2 included for purposes of explanation, shows the response characteristic of the multiplexer/demultiplexer of Fig. 1;

Figure 3 shows a multiplexer/demultiplexer embodying the present invention; and

Figures 4 and 5 show portions of modified embodiments of the invention.

Referring to the drawings, Fig. 1 shows a known reflection-type, diffraction-grating, wavelength division multiplexer/demultiplexer 10. For purposes of illustration and explanation, the device is shown operating as a demultiplexer comprising a common input multimode optical fibre 9, and a linear array of output multimode optical fibres 11–1. 11–2 . . . 11–6. Signals at different wavelengths λ_1, λ_2 . . . λ_6, delivered by fibre 9, are spatially separated by means of a blazed, reflection-type diffraction grating 13. A lens 12, interposed between the fibre array and the grating, serves to focus the several optical beams.

In operations, wave energy at wavelengths λ_1, λ_2 . . . λ_6, emitted by fibre 9, is focused onto grating 13 from which it is selectively reflected. The resulting intensity distribution, as a function of distance D along the fibre array, is shown in Fig. 2. Measured from some arbitary reference point, 0, the first intensity peak at wavelength λ_1 occurs at a distance D_1 along the D axis. Similarly, peaks at wavelengths λ_2, λ_3 . . . λ_6 occur at distances d_2, d_3 . . . d_6. Thus, the several components of the incident signal, each corresponding to a separate signal channel, can be spatially separated by placing a fibre at the focus point for each of the diffracted signals, as shown in Fig. 1. Advantageously, the grating 13 is designed so that the distance D between intensity peaks is equal to the outside diameter of the fibres. This makes for the most efficient use of the available optical bandwidth. The channel bandwidth is a function of the core diameter, *c*. For multimode fibres, where the ratio of the core diameter to the cladding diameter is approximately 0.5, efficient use is thus made of the available bandwidth. By contrast, the core-to-cladding ratio for single mode fibres is very much lower. Typical core and cladding diameters are 8μm and 125μm, respectively, so that the utilization efficiency is reduced from 50 percent to about 6 percent. What is required is a means for increasing the packing density of the channels. This is accomplished by interposing a converging waveguide array between the fibres and the reflecting grating, as shown on Fig. 3. More specifically, the multiplexer/demultiplexer comprises an array 31 of input /output fibre sections 31–1, 31–2 . . . 31–n; an integrated optic converging waveguide array 30; a lens 32; and a blazed diffraction grating 34. Advantageously, each

fibre section is terminated with a suitable connector (not shown) for making connection to the system fibres. In this illustrative embodiment, the lens 32 is a 1/4 pitch grin lens which can be more conveniently coupled to the waveguide array than a discrete lens. A wedge 33 is included for more efficient coupling between lens 32 and grating 34.

As indicated above, close packing of the signal channels is impossible using conventional single mode fibres owing to the small core-to-cladding ratio. The use of nonstandard single mode fibres with very thin claddings, and corresponding larger core-to-cladding ratio, would present formidable handling difficulties. The use of an integrated waveguide array avoids both of these problems. As shown, each of the fibres 31–1, 31–2 . . . 31–n is terminated at one end of one of the waveguides 30–1, 30–2 . . . 31–n. The waveguide array converges so that at the lens end the spacing between waveguides is much smaller than the cladding diameter of the standard single mode fibre. Crosstalk will ultimately limit the waveguide packing density. However, crosstalk is small for spacings of order twice the mode size and can be further reduced, if necessary, by placing grooves in the waveguide substrate between adjacent waveguides, as illustrated in Fig. 4. In this Figure, the end of the array adjacent to the lens is shown. For purposes of illustration, five waveguides 41, 42, 43, 44 and 45 are shown embedded in a suitable substrate 46. To more effectively isolate the several channels, grooves 50, 51, 52 and 53 are formed in substrate 46 in the region between adjacent waveguides. Greater isolation can be realised by making the propagation constants of adjacent waveguides unequal.

The multiplexer described hereinabove can be integrated onto a common substrate. One dimensional focusing and diffraction techniques for thin-film optical waveguides have been demonstrated using glass substrates. The use of an electrooptically active substrate, such as $LiNbO_3$, would also allow the integration of other circuit functions on the same substrate. For example, Fig. 5 shows a further modification of the waveguide array in which modulators 61–1, 61–2, 61–3 and 61–4 have been placed along the respective waveguides 60–1, 60–2, 60–3 and 60–4. In this embodiment, cw signals at wavelengths λ_1, λ_2, λ_3 and λ_4 are coupled into the waveguide array 60. The output along waveguide 65 comprise wavelength multiplexed modulated signals.

CLAIMS

1. An optical multiplexer or demultiplexer comprising: a linear array of single mode optical input/output fibres, a diffraction grating for selectively coupling optical wave energy between one of the fibres and the others of the fibres, a lens for focusing said coupled energy and an intergrated optic, converging waveguide array interposed between the fibres and the lens.

2. A multiplexer or demultiplexer as claimed in claim 1 wherein the waveguide array comprises a plurality of waveguiding strips embedded in a substrate of lower refractive index and the distance between adjacent waveguiding strips decreases from a maximum at a first end of the waveguide array, adjacent to the fibres, to a minimum at a second end of the waveguide array, adjacent to the lens.

3. A multiplexer or demultiplexer as claimed in claim 2 including grooves extending into the substrate in the regions of the second end between adjacent waveguiding strips.

4. A multiplexer or demultiplexer as claimed in claim 2 or claim 3 wherein the substrate is of an electrooptic material.

5. A multiplexer or demultiplexer as claimed in claim 4 including means for modulating an optical signal included along waveguiding strips of the waveguide array.

6. A multiplexer or demultiplexer as claimed in any of the preceding claims wherein the propagation constants of adjacent waveguides in said array are unequal.

7. A multiplexer or demultiplexer substantially as herein described with reference to the accompanying drawings.

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