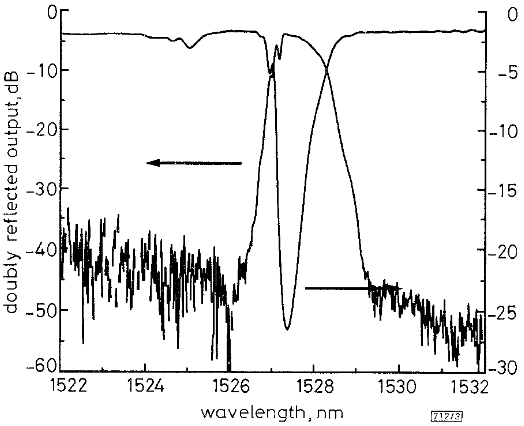

Fig. 3 *Spectral output of dropped channel (port 6) and transmitted channels (port 5) for input at port 1*

A transmitted isolation of -25dB and sidelobe level of -40dB are achieved for a 1nm dropped channel 3dB width

and fibre-waveguide coupling loss. In an ideal device, the insertion loss is expected to be limited by UV-induced loss of <0.2dB for each grating pair and fibre waveguide coupling losses of < 1dB. The dropped channel spectrum has a 3dB width of 1nm, which is significantly narrower than the individual Mach-Zehnder grating widths of 1.4nm in Fig. 2. This narrowing is due to the multiplication of filter functions which have sloped sidewalls. The insertion loss of ~3.7dB is caused by similar factors to those found in the case of the transmitted signal, as well as by grating fabrication errors which only affect reflected light [4]. The double filtering is clearly demonstrated by the extremely low sidelobe levels of -40dB within 200GHz of the peak. As expected, this level is two times lower than the single device sidelobe levels in Fig. 2. Double filtering in transmission has also been measured by coupling light into port 4 and examining the output from port 3. A transmitted channel isolation of -40dB was obtained.

Because of its reduced sidelobe levels and improved dropped channel transmitted isolation, this device represents significant progress in Mach-Zehnder based add-drop filters. Further optimisation in coupler design and grating fabrication will result in additional performance enhancements. The planar waveguide geometry provides an inherently stable interferometer that is relatively simple to fabricate using established processing techniques. This work demonstrates that a small wafer area can yield a high quality device and suggests that silica based planar waveguide devices are a viable, low cost add-drop technology.

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Statically-phase-compensated 10GHz-spaced arrayed-waveguide grating

H. Yamada, K. Takada, Y. Inoue, Y. Ohmori and S. Mitachi

Indexing term: Grating demultiplexers

The crosstalk of an arrayed waveguide grating multiplexer with a channel spacing of 10GHz was reduced by trimming a-Si films deposited on the arrayed waveguides. This static phase compensation enables a stable multiplexer to be made which features a low crosstalk of < -30dB without any external phase control.

Introduction: The arrayed-waveguide grating (AWG) multiplexer is a key device for wavelength division multiplexing. A channel crosstalk of ~ -30dB has been realised in an AWG multiplexer with a channel spacing of larger than 50GHz [1, 2]. However, a 10GHz-spaced AWG multiplexer has shown a higher crosstalk due to large phase errors, which result from the deviation in the optical path length of the arrayed-waveguides [3]. We have demonstrated phase error compensation in a 10GHz-spaced AWG multiplexer using thermo-optic phase shifters [4, 5]. This method requires an electric power of ~10–20W and temperature control of the device, which makes long-term stability impossible to achieve without feedback control.

This Letter describes an effective way to compensate statically for the phase errors of an AWG multiplexer by which the compensated phase is maintained immediately after phase adjustment. A stable, stand-alone 10GHz spaced AWG multiplexer with a channel crosstalk of less than -30dB has been realised.

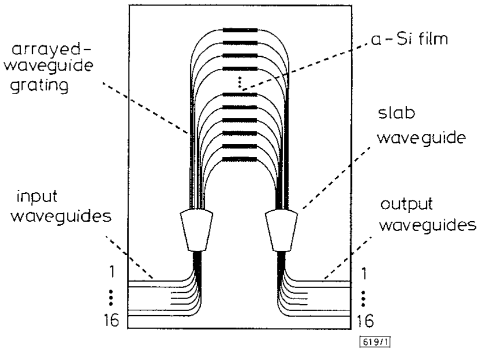

Fig. 1 *Arrayed-waveguide grating multiplexer with a-Si film*

Experiment and result: Fig. 1 shows the configuration of an arrayed-waveguide grating multiplexer fabricated for static phase compensation. It consists of 16 input/output waveguides, two concave slab waveguides and an arrayed-waveguide grating incorporating 64 waveguides with a path difference of 1271 μm between adjacent waveguides. This device was fabricated using silica-based planar lightwave circuit (PLC) technology [6]. To reduce the crosstalk of the AWG, we used the photoelastic effect with a-Si film for static phase error compensation. The a-Si films 95μm wide, 6mm long and 7μm thick were deposited on all the arrayed waveguides by magnetron sputtering for phase adjustment. The width of the a-Si films was designed so that the phase change after a-Si film trimming was the same for the TE and TM modes [7].

Phase error compensation was undertaken based on the principle reported in [4]. First, the phase errors were measured by using Fourier transform spectroscopy with a low-coherence interferometer [8]. Secondly, the phases were individually adjusted by trimming the a-Si film so as to offset the measured phase errors. Phase trimming was performed by partly removing the a-Si film from the surface of the cladding with an Ar ion laser. The experiment consisted of monitoring the phase error distribution when TE mode light was launched into the 8th input port and detected at the ninth output port.

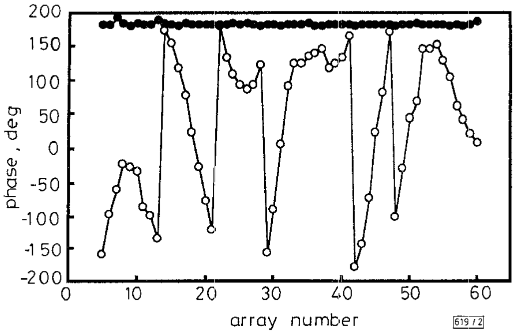

Fig. 2 *Phase error distribution for the TE mode before and after phase compensation*

—O— before
—●— after

The initial phase error distribution and transmission spectrum for the TE mode are shown, respectively, by the open circles in Fig. 2 and the broken line in Fig. 3. The initial channel crosstalk was degraded by the phase errors which were distributed over 360°. We then individually trimmed 56 of the a-Si films. The four films at each end of the array were not trimmed as they are less effective for crosstalk reduction because of low power distribution. The phase of each arrayed-waveguide could be individually adjusted, because the distance between adjacent arrayed-waveguides was designed to be larger than 500μm. However, the phase change per unit length of trimming ranged from 65 to 87 degree/mm depending on the location of the a-Si films, and this leads to errors in the compensated phase. In order not to exceed the predetermined amount of compensated phase, the trimming length was designed to be equal to 90% of the length required when the phase was assumed to be controlled at a maximum rate of 85 degree/mm. The procedure was repeated until the phase errors were reduced to < 10°.

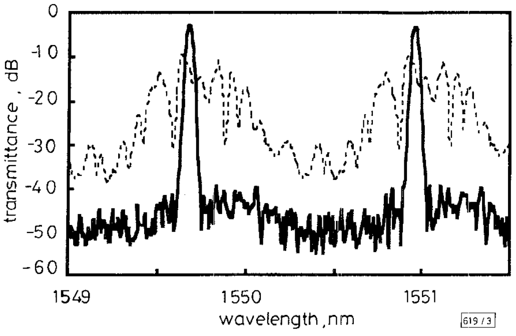

Fig. 3 *Transmission spectrum for the TE mode before and after phase compensation*

– – – – before
——— after

The filled circles in Fig. 2 and the solid line in Fig. 3 show the phase error distribution and the transmission spectrum for the TE. The phase errors were successfully reduced to an RMS of 2°, and the channel crosstalk was drastically reduced to less than –36dB. Fig. 4 shows the wavelength response characteristics for all 16 output ports of the phase-compensated multiplexer. Each channel was separated with a wavelength spacing of 0.08nm, which corresponds to an optical frequency spacing of 10GHz. The channel crosstalk for 16 output ports was < –31dB and the on-chip loss at the centre wavelength of the pass band ranged from 3.0 to 5.3dB. This method offers a stable, stand-alone multiplexing operation with a low crosstalk of < –30dB, because the compensated phase is maintained immediately after adjustment. Therefore, the phase-compensated AWG with a channel spacing of 10GHz will be used as widely as AWGs with 100GHz spacing for dense WDM applications.

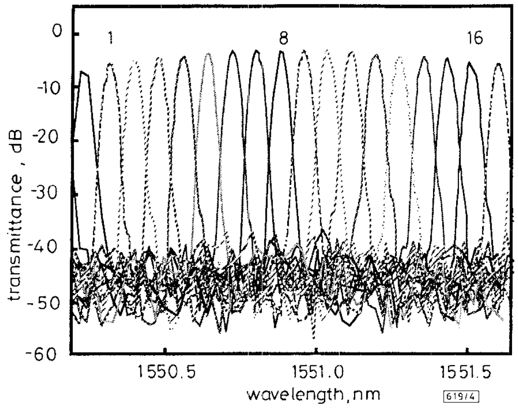

Fig. 4 *Wavelength response for all 16 output ports of phase-compensated multiplexer*

The phase errors for the TM mode could not be compensated for in this experiment because the initial phase error distribution of the fabricated AWG for the TE and TM modes were different. This polarisation dependence of the phase errors is the result of a slight imhomogeneity in the photoelastic effect induced by a-Si films. It could be compensated for by using a-Si films for birefringence control before phase error compensation.

Conclusion: A 16 channel 10GHz-spaced arrayed-waveguide grating multiplexer with a-Si film was fabricated in order to compensate statically for phase errors. The phase errors were statically reduced to an RMS of 2° by measuring them using an optical low-coherence interferometer and by trimming the a-Si films. This method provides a stable, stand-alone 10GHz spaced arrayed-waveguide grating multiplexer with a channel crosstalk of < –30dB.

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1.3μm InGaP/InAsP MQW lasers with large spot-size and low loss fibre chip coupling fabricated by a standard buried heterostructure process

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Indexing terms: Semiconductor junction lasers, Semiconductor quantum wells, Optical couplers

1.3μm large spot-size laser diodes without a mode converter fabricated by conventional buried heterostructure laser process, and using MQW core structure with low effective refractive index are demonstrated. The devices show low coupling losses to cleaved fibre, good alignment tolerances, and high temperature characteristics.

Low cost optical transmitter modules are key elements for the implementation of optical fibre in the distribution networks up to the subscribers. As the largest part of the transmitter module cost is attributed to the packaging and, particularly, to the fibre chip coupling with submicrometre alignment accuracy, a narrow beam divergence laser diode providing high coupling efficiency and relaxed alignment tolerances and fabricated with standard processes, is an attractive device. During the past few years much attention has been paid to the integration of mode size converters with active devices in order to improve the coupling efficiency. Mode size expansion has been achieved by continuously tapering the active waveguide cross-section in order to transform the mode shape and size to mach that of the fibre. A number of techniques for tapering the width [1], the thickness [2], or the composition [3] of the active waveguide have been proposed. These approaches yield good reduction in output beam divergence. However, they generally suffer from several drawbacks, such as degraded lasing characteristics and long cavity devices, due to the additional tapering section. They also involve procedures for tapering that complicate device fabrication and result in increased cost.

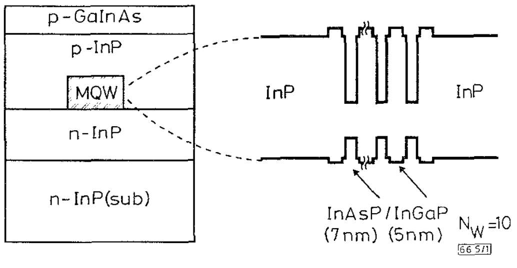

Fig. 1 *Schematic diagram of MQW buried stripe (BRS) laser structure*

We present a simple expanded output mode laser without a spot-size transformer. The laser spot-size expansion is achieved by decreasing the effective refractive index step between the core and cladding, using a InAsP/InGaP multiquantum well structure. The major advantage of this approach is that the laser can be fabricated with conventional buried heterostructure technology with no inherent resolution limits and no need for additional sophisticated etching or epitaxial techniques, avoiding any significant cost increase of the laser chip. Therefore, this approach is suitable for mass production. The fabricated LDs show good lasing characteristics and low loss coupling of < –4.3dB into a cleaved single mode fibre with good misalignment tolerance.

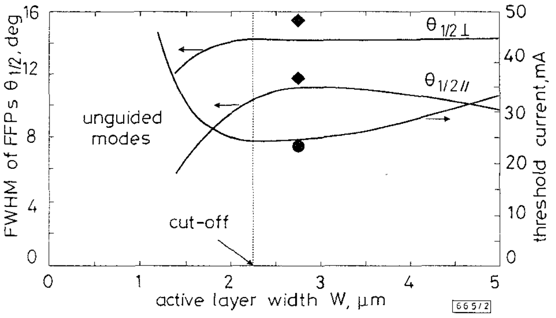

Fig. 2 *Threshold current and full widths at half maximum of far-field patterns against active layer width*

●, ◆ experiment

In a conventional semiconductor laser diode the optical mode inside the cavity is necessarily small due to the large refractive index difference between the core and cladding for higher confinement to the active region, which results in a large output divergence angle (FWHM ~30°// 50°⊥). To increase the laser mode size, the core cross-section can be reduced [4], or a multilayer core structure can be used and a large bandgap semiconductor material with a refractive index equivalent or lower than that of the cladding incorporated into the core region. We use a compensated strained quantum well InAsP/InGaP structure as a core region.

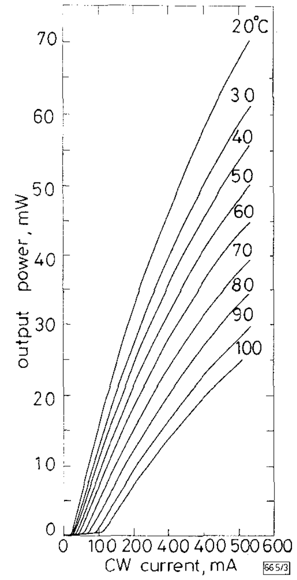

Fig. 3 *Light output against current at different temperatures*

L = 260μm, as-cleaved *HR* 0.95

The strained InGaP material used as barrier has a bandgap wavelength of 0.9μm and a refractive index lower than that of the InP, which considerably reduces the effective refractive index of the core, without a significant decrease of the modal gain, due to the higher gain of the MQW structure. A schematic diagram of the device structure is shown in Fig. 1, which consists of a stack of 10 compressively strained 7nm thick InAsP wells (1.7%) and 5nm thick InGaP tensile barriers (–1.4%) grown by MOCVD atmospheric pressure. A very thin layer of InP with just two monolayers was inserted between the well and barrier in order to prevent lateral thickness undulation and improve the interface quality between the wells and the barriers [5]. The BH lasers were fabricated by reactive ion beam etching (RIBE) for the mesa