The theoretical intensity transmittance also has Gaussian shape as
becomes -12dB. An additional loss of 6.4dB is caused by cutting

frequency. The peak transmittance is -5.6dB. Fig. 4 shows the spec-
biner) t 0.1 (dB)
tral transmittances of the filter when

the waveguide propagation loss. The total waveguide length of the
transversal filter is evaluated to be -1.9dB.

To confirm the signal processing capabilities, sinc-type and
Gaussian-type spectral filter responses have been synthesised.

Fig. 3 shows the spectral transmittances of the filter when \( g_n = 1 \)
for all \( n \). Since the functional shape of \( g_n \) and the spectral trans-
mittance \( G \) are connected by a Fourier transform relationship,
the theoretical intensity transmittance is expressed by

\[
T = |G|^2 = \left( \frac{1}{N} \right)^2 \left( \frac{\sin(N\phi/2)}{N\sin(\phi/2)} \right)^2 \quad (3)
\]

where \( \phi = \frac{2\pi n}{\lambda AL} = \frac{2nf}{FSR} \) and \( f \) denotes the optical frequency. The peak transmittance is -5.6dB. Fig. 4 shows the spectral transmittances of the filter when \( g_n \) has the following Gaussian profile:

\[
g_n = \exp \left[ -\frac{(n - 7)(n - 8)}{16} \right] \quad (n = 0, 1, \ldots, 15) \quad (4)
\]

The theoretical intensity transmittance also has Gaussian shape as
shown by the dotted line in Fig. 4. The peak transmittance becomes -12dB. An additional loss of 6.4dB is caused by cutting out the signal power in each tap arm to form Gaussian tap coefficients. It is shown from Figs. 3 and 4 that an arbitrary shape of the filter characteristics can be realised by the present transversal filter.

**Conclusion:** The fabrication of a fully integrated coherent optical transversal filter has been reported. It is confirmed that the collective summation of complex electric fields is obtainable by using an

MII combiner. Programmable spectral filters and chromatic dispersion equalisers can be realised by using the present transversal filter. Experiments are now in progress and the results will be reported in the future.

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**References**


7 IIDA, Y., HIBINO, Y., OKAZAKI, H., and OCHNO, Y.: '10-m long silica-based waveguide with a loss of 1.7 dB/m', IPR '95, Dana Point, CA, 1995, Paper FTB6C

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**Grating formation in BGG31 glass by UV exposure**


A three-dimensional index variation grating in bulk BGG31 glass written using neither hydrogen loading nor germanium doping is demonstrated. This material is useful for fabricating ion-

exchanged waveguides, and its photosensitivity to ultraviolet (UV)
radiation at 248nm has not been previously explored. Intensity measurements of the Bragg diffracted spots indicated a maximum index variation (\( \Delta n \)) of \( 4 \times 10^{-6} \).

**Introduction:** The field of optical communications has recently experienced a host of new devices to allow for higher bit rates. One area of innovation has been in the research of ion-exchanged waveguides [1], and incorporating Bragg gratings into such devices could lead to a great range of applications. Permanent index changes for gratings written in Ge-SiO_2_ glasses have been reported [2]. Photobleaching has also been performed in a K'-exchanged waveguide with the 351mm line from an Ar* laser [3]. However, the photosensitivity was reportedly obtained by \( \gamma \)-ray irradiation pretreatment. In the waveguide material discussed in this Letter, there are no Gedopants [4] and no pretreatment of any kind, including hydrogen loading, thus allowing easier and cheaper fabrication.

We report the writing of a diffraction grating in a 2mm thick glass sample used for making A* ion-exchanged waveguides by exposure to radiation from a 248nm KrF excimer laser, without germanium doping nor hydrogen loading. BGG31 is a glass of the system SiO_2_/B_2/O_3_/Al_2/O_3_/Na_2/O/F, with 12.5molNa_2O. The three-dimensional written gratings are evidence that neither ge-
For the grating inscription, the BGG31 glass sample was placed directly under a phase mask with a pitch of 1049.28nm (IBSEN Micro Structures A/S) and exposed with the excimer laser at 248nm (Lambda Physik Complex 110). For best results, the glass was placed in direct contact with the phase mask and exposed for 10ms with 0.84J/cm² per pulse at 50Hz over an area of 2cm × 2mm. Before exposure, the beam was collimated in the long dimension (perpendicular to the phase mask rulings) and slightly focused in the short dimension. Other trials were carried out with gaps of 125 and 250μm between the phase mask and the sample, but in each case the diffraction spots from the Ar⁺ laser probe were reduced in intensity. This is consistent with reports [5, 6] that it is not the temporal coherence that limits the fringe visibility with mask/glass (or fibre) separation, but the spatial coherence.

The diffraction orders from the phase mask obey the equation

\[ \Delta \lambda_{\text{mask}} \sin \theta_{\text{m}} = m \lambda \] (1)

where \( m \) is the diffraction order, \( \lambda = 248\text{nm} \), and \( \Delta \lambda_{\text{mask}} \) is the mask period = 1049.28nm. Each pair of beams produces an index variation grating in the material with a unique angle \( \phi \). Fig. 2 shows an example of a grating produced with the \(-2, +1\) orders. The angle \( \phi \) for a given grating is determined as the bisector of the angle between the propagation directions of any two orders, denoted \( m_1 \) and \( m_2 \). The \( \pm 1 \) orders produce gratings with \( \phi = 0 \), as will the \( \pm 2 \) orders, \( \alpha \) is the Bragg angle, measured as the angle of the incident (or reflected) ray with the tangent to the grating lines.

Characterisation of the written gratings was accomplished by probing these gratings with the 476nm line from an Ar⁺ laser operating at ~50mW. Evidence for a volume grating was that a very precise incident angle \( \theta_{\text{m}} \) was needed to observe Bragg diffraction (Fig. 2). If only surface gratings had been produced by the excimer laser, then Bragg diffraction would have occurred at a continuum of angles. The Bragg condition for these photowritten gratings is

\[ 2 \frac{\Delta \lambda_{\text{mask}}}{m_1 - m_2} \cos \phi \sin \alpha = m \lambda \] (2)

where the term in brackets is the actual period of the desired grating, derived from the intensity distribution of any two diffracted orders \( m_1 \) and \( m_2 \), \( m \) is the diffraction order from the probe, and here \( \lambda = 476\text{nm} \). \( \theta_{\text{m}} \) and \( \theta_{\text{out}} \) can be obtained from \( \alpha \) in eqn. 2 and account for the background material index of 1.4.
waveguides have been performed [8], and better than 90% transmission dips at a Bragg wavelength of 1.53μm have been obtained.

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**References**


**Multi/demultiplexer consisting of one parent 10GHz-spaced AWG and eight subsidiary 100GHz-spaced AWGs**

K. Takada and K. Okamoto

A 320-channel 10GHz-spaced multi/demultiplexer is reported which is realised by connecting eight 100GHz-spaced AWGs in parallel to one 10GHz-spaced AWG. The subsidiary AWGs are conventional 100GHz-spaced AWGs and only one phase-compensated 100GHz-spaced AWG is needed. The configuration is more promising for developing an ultra-dense multi/demultiplexer than that reported previously in which sixteen 10GHz-spaced AWGs were used.

**Introduction:** Large-scale multi/demultiplexers with narrow channel spacing are attractive for use in increasing the capacity of wavelength division multiplexing (WDM) systems. We demonstrated a 320-channel 10GHz-spaced multi/demultiplexer consisting of one parent 100GHz-spaced arrayed-waveguide grating (AWG) and 16 subsidiary 10GHz-spaced AWGs [1] thus showing the potential of parallel connection for increasing the number of narrow channels. In practice, however, it is rather difficult to use so many 10GHz-spaced AWGs because a sophisticated phase compensation technique [2] is needed to reduce the crosstalk between the AWGs. We report that the same 320-channel multi/demultiplexer can be constructed by connecting eight conventional 100GHz-spaced AWGs in parallel with only one 10GHz-spaced AWG. This configuration greatly reduces the required number of AWGs.

Configuration: The configuration of our multi/demultiplexer is shown in Fig. 1. It consists of a parent 10GHz-spaced AWG and eight identical 100GHz-spaced 32×32 AWGs, AWGk (k = 1, 2, ..., 8). The ports on the left and right sides of each AWG are denoted as the input and output ports, respectively, and they are numbered 1, 2, ... from top to bottom. Input port 8 of the parent AWG was used as the multi/demultiplexer input port, and every output port was connected to either the input or output port of AWGk as follows: Output port 2k–1 was connected to input port 16 of AWGk through optical fibres. Output ports 2k (k = 1, 2, ..., 8) were connected to output ports 20, 20, 17, 19, 16, 16, 13, and 18 of AWGk (k = 1, 2, ..., 8), respectively, through optical fibres.

Gaussian passbands obtained at different diffraction orders from output port k (k = 1, 2, ..., 16) of the parent AWG, input port 8 of which is used for light incidence, appear repeatedly at FSRk = 10GHz intervals and the group is named Nk. Changing the output port shifts the group by an integer multiple of Δν = 10GHz, as shown in the upper part of Fig. 2. Flat-top passbands, fn (m = 1, 2, ..., Nk) obtained from all Nk = 32 output ports of AWGk, input port 16 of which is used for light incidence, are arranged with a bandwidth of BWk = 80GHz and are arranged with Δν = 10GHz intervals, as shown in the lower part of the Figure. Each passband is used to block unwanted passbands in Nk.

**Principle of operation:** The passbands obtained from Nk output ports of AWGk in the multi/demultiplexer are given by multiplying FSRk with fn (m = 1, 2, ..., Nk). Under the condition that the bandwidth BWk < FSRk, one Gaussian passband at most in Nk is allowed to pass through every fn. The number of unblocked and available passbands from AWGk is Nk × Δν/FSRk = 20 and this group of at least 160 Gaussian passbands is obtained from all the output ports of AWGk (k = 1, 2, ..., 8). Since the cyclic condition of Nk × Δν = FSRk is approximately satisfied for AWGk, the free spectral range of which is FSRk almost the same passbands as fn (m = 1, 2, ..., Nk) are obtained from its Nk input ports when an output port other than 16 is used for light incidence. Therefore, another group of 160 passbands is obtained from all input ports of AWGk (k = 1, 2, ..., 8). The bandwidth and cyclic conditions ensure that the two groups are combined to give 320 Gaussian passbands arranged at Δν intervals.

There is at least one output port m in AWGk for every value of k, such as output port 20 of AWG1 as shown in Fig. 2, the pass-