Beam-adjustment-free crosstalk reduction in 10GHz-spaced arrayed-waveguide grating via photosensitivity under UV laser irradiation through metal mask

K. Takada, T. Tanaka, M. Abe, T. Yanagisawa,
M. Ishii and K. Okamoto

The crosstalk of a 10GHz-spaced 32 channel arrayed-waveguide grating has been reduced from −17 to −30dB and from −16 to −27dB for the TE and TM modes, respectively, via the photosensitivity under 193nm ArF excimer laser irradiation. A metal mask with a window was placed on the arrayed waveguides and the unmasked arrayed waveguides were irradiated until the crosstalk was reduced to the desired value. This technique means that fine adjustment of the laser beam on individual arrayed waveguides is no longer necessary.

Introduction: Narrow-channel arrayed-waveguide gratings (AWGs), e.g. a 10GHz-spaced AWG, are important devices in the construction of ultra-dense multi/demultiplexers [1]. Since a narrow-channel AWG has a higher channel crosstalk than a conventional 100GHz-spaced AWG, several methods have been developed for externally compensating for the phase errors of all the arrayed waveguides [2]. Although the crosstalk was greatly reduced, demonstrating the potential of external phase compensation, a laser beam had to be focused on each arrayed waveguide and this made the compensation system rather complicated and made it more difficult to compensate for the phase errors of all the waveguides as the number of waveguides increased.

In this Letter we report a new method for externally controlling the phases of all the arrayed waveguides simultaneously by utilising their photosensitivity and changing their refractive indexes under UV irradiation [3]. The method involves placing a metal mask with a window on the arrayed waveguides. We then irradiate the unmasked waveguides with a UV laser until the crosstalk is reduced to the desired value. Fine adjustment by focusing a laser beam on the individual waveguides is no longer required.

Experimental procedure: The numbers of arrayed waveguides and input/output waveguides in the test 10GHz-spaced AWG were 81 and 32, respectively. We measured the phase error ϕ_k of each arrayed waveguide k ($k = 1, 2, ..., 81$) using an optical low coherence technique [4] with an accuracy of ± 3°. Basically, the channel crosstalk can be reduced by adding a phase of $\phi - \phi_k$ to arrayed waveguide k and setting the resultant phase error to a constant value of ϕ [2]. We induced the additional phases by means of the refractive index change resulting from photosensitivity under UV laser light irradiation [3]. We formed the window by etching a 20μm thick metal plate which we then placed on the arrayed waveguides in such a way that the length of the unmasked k waveguide was proportional to $\phi - \phi_k$. When the light beam was normally incident on the metal plate without being focused, it passed through the window and irradiated the desired waveguide region uniformly.

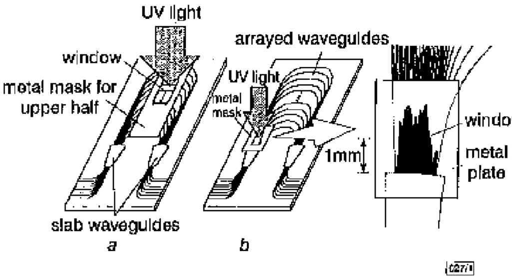

Fig. 1 *Schematic diagram of external phase control of AWG by 193nm excimer laser irradiation through metal mask*

a First compensation
b Second compensation

Since the crosstalk of the AWG we used was rather high and had a large variation ranging from 0 to π rad in its phase error distribution, we reduced it by carrying out the following two steps, as shown in Fig. 1. First, we made two metal masks with windows (1cm high and 4 mm wide) for the upper and lower regions near the centre of the arrayed waveguides and we irradiated each window for 48min. The irradiation time was obtained from the rate of refractive index change due to photosensitivity. Actually, there were variations in the laser power density over its cross-section and this made it rather difficult to achieve fine phase control of each waveguide with the two masks. After reducing the large variation in the first stage of compensation, we then carried out a more precise compensation by making a mask with a smaller window for the waveguides near the input slab waveguide, as shown in Fig. 1. This was because the arrayed waveguides converged at the slab waveguide and the laser beam could irradiate the unmasked region uniformly.

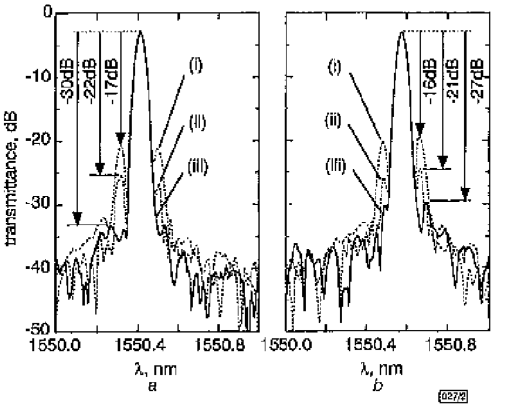

Fig. 2 *Transmission spectra for TE and TM modes before and after phase compensation*

Complete phase compensation was accomplished by first (rough) and second (fine) stage compensation
a TE mode
b TM mode
(i) before
(ii) first stage
(iii) second stage

Experimental results: The arrayed waveguides were irradiated with 193nm ArF excimer laser light at an irradiance of 150mJ/pulse and with a pulse repetition rate of 20Hz [5]. The levels of the sidelobe components of the transmission bands of the original AWG before compensation in the TE and TM modes were −17 and −16dB, as shown in Fig. 2*a* and *b*, respectively. Here the light from an amplified spontaneous emission (ASE) source was launched from input port 16 of the AWG and the spectrum of the light from input port 16 was measured. After the approximate compensation in the central regions of the arrayed waveguides, the sidelobe components were reduced to −22 and −21dB, in the TE and TM modes, respectively.

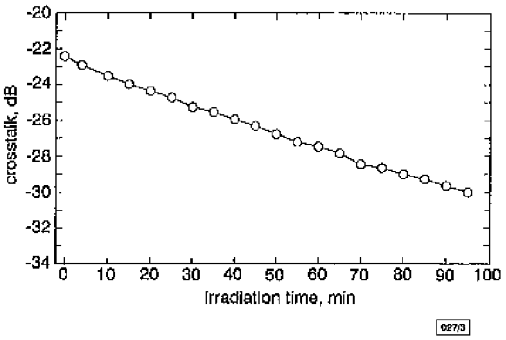

Fig. 3 *Crosstalk change against irradiation time with 193nm ArF excimer laser when metal mask for fine crosstalk compensation was placed on arrayed waveguide*

The phase errors around both ends of the arrayed waveguides in the TE mode after the approximate compensation were at most 0.5rad greater than those in the TM mode. We designed a metal mask for fine compensation for the TE mode and measured the change in the sidelobe component on the left side of the passband peak in Fig. 2*a*, (referred to as the crosstalk value), against irradiation time, as shown in Fig. 3. The crosstalk value changed almost linearly with irradiation time from -22 to -30dB. We stopped the irradiation after 95min, but a curve fit to the data showed that the crosstalk would reach -35dB for a 200min irradiation. This value could be achieved with a 95min irradiation by doubling the size of the window since the irradiation would remain uniform over the enlarged window. Although the window was designed for the TE mode, the crosstalk in the TM mode decreased from -21 to -27dB as shown in Fig. 2*b*.

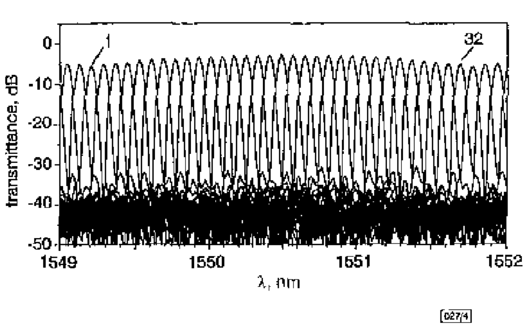

Fig. 4 *Transmission spectra of 32 channels (1, 2, ..., 32) of phase-compensated 10GHz-spaced AWG*

Fig. 4 shows the demultiplexing characteristics of all 32 channels in the TE mode of the phase-compensated 10GHz-spaced AWG. Each channel was separated with a wavelength spacing of 0.08nm, or 10GHz. The sidelobe components changed between -33 and -27dB as the output port changed and the on-chip loss at the centre wavelength of the passband ranged from 3 to 6dB.

Conclusion: We have reported a new phase control method that externally reduces the channel crosstalk of an AWG via the photosensitivity under UV laser irradiation through a metal mask. The method involves placing a metal mask with a window on the arrayed waveguides and irradiating the unmasked waveguides with the laser beam. With a 193nm ArF excimer laser we succeeded in reducing the crosstalk of a 10GHz-spaced 32 channel AWG from -17 to -30dB, and from -16 to -27dB, for the TE and TM modes, respectively. This method has the following advantages: since all the waveguides are compensated simultaneously, the time needed to complete the compensation is unaffected by the number of waveguides; fine adjustment to focus a laser beam to individual waveguides is no longer required and this makes the system much simpler.

20 October 1999
Electronics Letters Online No: 20000021
DOI: 10.1049/el:20000021

K. Takada, T. Tanaka, M. Abe, T. Yanagisawa, M. Ishii and K. Okamoto (*NTT Photonics Laboratories, Nippon Telegraph and Telephone Corporation, Tokai-mura, Ibaraki-ken, 319-1193, Japan*)

References

1 TAKADA, K., YAMADA, H., and OKAMOTO, K.: '320-channel multiplexer consisting of a 100GHz-spaced parent AWG and 10GHz-spaced subsidiary AWGs', *Electron. Lett.*, 1999, **35**, pp. 824–826

2 YAMADA, H., TAKADA, K., INOUE, Y., OHMORI, Y., and MITACHI, S.: 'Statically-compensated 10GHz-spaced arrayed-waveguide grating', *Electron. Lett.*, 1996, **32**, pp. 1580–1582

3 HILL, K.O., FUJII, Y., JOHNSON, D.C., and KAWASAKI, K.: 'Photosensitivity in optical waveguides: application to reflector filter fabrication', *Appl. Phys. Lett.*, 1978, **32**, pp. 647–649

4 TAKADA, K., YAMADA, H., and INOUE, Y.: 'Optical low coherence method for characterizing silica-based arrayed-waveguide grating multiplexers', *J. Lightwave Technol.*, 1996, **14**, pp. 1677–1689

5 TANAKA, T., TAKAHASHI, H., OGUMA, M., HASHIMOTO, T., HIBINO, Y., YAMADA, Y., ITAYA, Y., and HILL, K.O.: 'Integrated external cavity laser composed of spot-size converted LD and UV written grating in silica waveguide on Si', *Electron. Lett.*, 1996, **32**, pp. 1202–1203

Experimental demonstration of new regeneration scheme for 40Gbit/s dispersion-managed long-haul transmissions

P. Brindel, O. Leclerc, D. Rouvillain, B. Dany, E. Desurvire and P. Nouchi

It is experimentally shown, for the first time, that optical 3R regeneration by synchronous modulation can be efficiently implemented in dispersion-managed transmission schemes. By taking advantage of the association of both techniques, 40Gbit/s single-channel transmission over > 10000km is demonstrated.

The expansion of a wide range of new services involves rapid growth in the transmission capacity of telecommunications networks. A key issue is the control of the quality of the transmission data along the whole link. Dispersion management (DM) appears to be a very powerful technique for enhancing the quality of WDM transmission systems, as shown in recent 10Gbit/s-based experiments [1, 2]. At higher bit rates (i.e. 40Gbit/s), inline optical regeneration based on both intensity and phase modulation (IM-PM) is a helpful and powerful tool for enabling error-free transmission over transoceanic distances [3, 4]. Owing to amplitude fluctuations induced by IM, a narrow bandpass optical filter must be added to the synchronous modulation. However, filters have been shown to be only of poor efficiency in stabilising the energy of a DM soliton [5, 6]. This is the reason why systems combining both techniques have never been demonstrated. To remove this limitation, we proposed in [7] the idea of a local periodic conversion between a DM pulse and a standard nonlinear Schrödinger (NLS) soliton pulse, thus restoring the filter efficiency for stabilising amplitude fluctuations. In this Letter, we experimentally demonstrate for the first time that 40Gbit/s optical 3R regeneration using synchronous modulation can be efficiently associated with DM soliton transmission when using the previously mentioned conversion scheme.

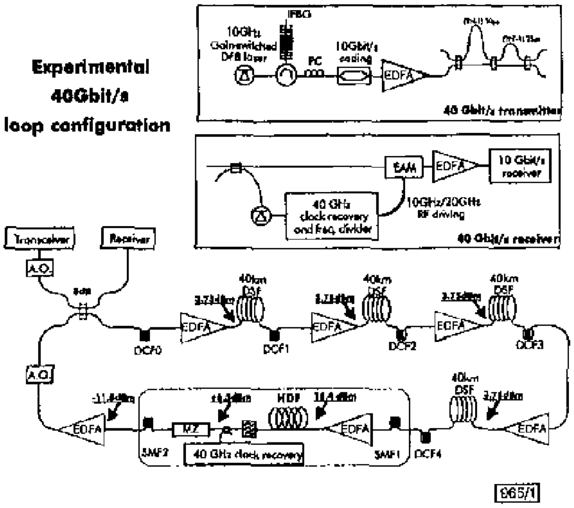

Fig. 1 *Experimental 40Gbit/s loop configuration for evaluation of regenerated DM soliton transmission*

Insets: transmitter and receiver

Fig. 1 shows the experimental setup including two insets which illustrate the transmitter and receiver. Pulses at a 10GHz repetition rate generated from a gain-switched distributed feedback (DFB) laser at 1555.75nm are compressed down to 6ps through a -30ps/nm fibre Bragg grating, coded with a $2^{15}-1$ PRBS at 10Gbit/s and optically time multiplexed to provide a 40Gbit/s data stream. At the receiver end, bit error rates (BERs) are measured at 10Gbit/s, after demultiplexing the 40Gbit/s data stream using a polarisation-insensitive electroabsorption modulator electrically driven by 20 and 10Gbit/s electrical sine waves.

The recirculating loop is shown in Fig. 1. The dispersion map is made of four spans consisting of 40km of DSF with a +2.25ps/nm/km dispersion, three DCF modules at -84.5ps/nm and another