contacts are alloyed AuGe/Ni/Au. The technology employs a three-level metal scheme, which also includes NiCr resistors and MIM capacitors. Circuit fabrication was performed by standard optical lithography using a modified 1-line GCA 5x stepper.

Test results: The circuit was tested, on-wafer, using RF probes. The test data signals were generated by a 10GbitIs bit-error-rate tester. The 4:1 multiplexer operated up to a maximum bit rate of 40Gbit/s, with input data level of 125mV peak-to-peak per channel, and a single-ended clock input level of 500mV peak-to-peak. The output eye diagrams at 40Gbit/s (both data and inverted data) are shown in Fig. 2. Proper multiplexer operation was verified by interleaving four 10Gbit/s input data channels, each four bits in length, and observing the resulting output bit pattern. (Bit-error rates were taken up to 30Gbit/s, the speed limit of a 1.4GHz demultiplexer IC, with an error rate being measured). The 40Gbit/s output bit pattern for pseudorandom input data is shown in Fig. 2b. Fig. 3 shows the output eye diagrams at an output rate of 30Gbit/s.

Fig. 2 Output diagrams (data and inverted data) at 40Gbit/s

Fig. 3 Output eye diagram (data and inverted data) at 30Gbit/s

The 4:1 multiplexer circuit occupies an area of 1 x 2mm², and dissipates 3.5W with a single power supply voltage of -7.5V. The power is dissipated mainly in the clock driver and emitter follower stages. A microphotograph of the 4:1 MUX is shown in Fig. 4.

Fig. 4 IC die microphotograph

Conclusion: A novel high-speed 4:1 MUX circuit topology, fabricated using advanced AlGaAs/GaAs HBT technology, has been described. The experimental multiplexer features special circuits to acquire, multiplex, regenerate and delay NRZ input data, and operated up to a maximum data rate of 40Gbit/s. The multiplexer architecture can be realized in any technology that supports CML, and may be extended to higher order multiplexers.

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All-fibre diode pumped, femtosecond chirped pulse amplification system

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Indexing terms: Fibre lasers, High-speed optical techniques

A totally integrated all-fibre femtosecond chirped pulse amplification scheme is described. Transform-limited 670fs pulses at a 3.1MHz repetition rate, derived from a diode pumped Yb:Er figure-of-eight fibre laser, are temporally stretched, amplified in a diode pumped Yb:Er fibre amplifier and recompressed to give 900fs pulses of 1.6nJ energy and an average power of 14mW. Chirped Bragg fibre gratings were used to stretch and recompress the pulses, in a novel configuration which minimizes loss.

High energy, low repetition rate pulses with high average powers are of considerable interest for many technological applications. Usually, mode-locked solid state bulk lasers appear to be more suitable for these applications than fibre lasers, since the latter typically operate with energies in the picowatt range. As a solution, the pulse energy and consequently the average power of Er-doped fibre lasers can be increased through angle pass gain received, for example, an ytterbium-erbium doped fibre ampli-

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YEDFAs are particularly attractive, as they exhibit high gain with a broad bandwidth, are relatively insensitive to the undesirable presence of nonlinearities, and now deliver saturated powers in excess of 30dBm. However, this amplification of femtosecond pulses using fibre amplifiers is linked to the harmful presence of nonlinearities, as a result of the high intensities obtainable in the core of the fibre for modest average powers. This can be avoided by chirping the pulse before amplification, which decreases the peak power of the pulse and reduces to some extent the effect of nonlinearities. The amplified pulses can then be recompressed leading to high peak powers. This technique is called chirped pulse amplification and has revolutionised the production of ultrahigh power, ultrashort pulses in bulk laser/amplifier systems [1]. It has also been used with erbium-doped fibre amplifiers [2], where a length of singlemode fibre and a diffraction grating pair were used to provide the initial linear chirp and recompression mechanisms, respectively. In this Letter we report an all-fibre, diode pumped, compact system for chirped pulse amplification, capable of generating pulse energies as high as 1.6nJ (currently limited by system nonlinearity) after recompression.

The experimental all-fibre configuration is shown in Fig. 1. Basically, it consisted of a femtosecond pulse source with fibre amplifiers placed between chirped Bragg fibre gratings with identical but opposite chirps. A diode-pumped, 'figure-of-eight' Yb:Er fibre laser was used as the low power, femtosecond pulse signal source. This device was operated just above threshold such that a single pulse per round trip was obtained. This provided an average output power of 30W in pulses at a 3.1MHz repetition rate with a measured (SHG autocorrelation) duration of 670fs. These pulses had a time-bandwidth product of 0.326, assuming a hyperbolic secant pulse shape (see Fig. 2) and operated broadly around 1.535µm.

The linearly chirped gratings were manufactured using the step chirp, phase mask technique [3]. This allows the production and reproduction of gratings with highly controlled, identical chirp parameters. The 98% reflecting gratings used were 7.5mm long with a -3dB bandwidth of 13.5nm, centred around 1.535µm, and exhibited a dispersion of 5.5 ps/nm. Operation of these identical gratings with equal but opposite chirp was simply achieved through reversing the direction of input to the device as a result of their reciprocal nature.

The pulses from the fibre laser source were directed via a 3dB coupler (with the free arm of the coupler monitoring the input) and dispersively chirped on reflection off the grating to a duration of ~20ps. The fusion coupler was constructed in-house (using an IRE Polus fusion coupler workstation) from dispersion shifted fibre and utilised minimum fibre lengths to minimise the effects of additional dispersion arising from the fibre. These low power pulses were then amplified in a diode pumped preamplifier and sequential power amplifier, with optical isolators placed before, between and following the amplifiers. The final amplifier was capable of delivering a saturated power in excess of 27dBm. The amplified, stretched pulses were directed in to the fibre Bragg grating of equal and opposite chirp to that of the input grating, via a fibre polarisation division multiplexer. This device, incorporating the grating, which we have described in [4], was operated in polarisation sensitive mode and included two polarisation controllers (PC) for correct operation of the device. Unlike the 3dB coupler used on the input side, where the loss was compensated for by gain in the amplifiers, any loss on the output coupling to the grating assembly (inherent in other schemes, [2, 6]) simply reduces the overall available pulse power. Consequently, this polarisation division multiplexer plus grating configuration with its overall loss of around 16dB (and potentially lower) is well suited to this power optimisation.

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observed in [5]. To overcome this problem, the grating should produce substantially longer pulses, thus reducing the peak power of the amplified pulses before recompression.

In conclusion we have demonstrated a diode pumped, all-fibre scheme for chirped pulse amplification. The pulses were re-compressed to subpicosecond durations with maximum average powers of ~50W and peak powers of 1.7 kW, which were effectively limited by the effect of self-phase modulation in the experimental configuration employed. This nonlinearity severely limited the operation of the device and to fully utilise the high power capability inherent to the system, considerably longer chirped pulses will be required. These improvements are being investigated, incorporating a diode pumped amplifier with a 30dBm average power delivery capability.

Following submission of this manuscript, a similar experimental scheme was reported by Galvanauskas et al. [6]. However, our configuration employs low loss gratings, does not exhibit high loss on output coupling through using our novel fibre polarisation division multiplexer [6] and has the capability of substantial high output power operation.

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Enhanced photosensitivity in lightly doped standard telecommunication fibre exposed to high fluence ArF excimer laser light


Indexing terms: Excimer lasers, Photosensitive effect

The core refractive index of Corning SMF-28 optical fibre exposed to ArF laser pulses increases with the square of the fluence per pulse. Bragg gratings with a refractive index modulation amplitude higher than 10⁻⁵ have been obtained. This is an order of magnitude improvement over previously reported values for this type of fibre in the absence of treatment to enhance the photosensitivity.

Photosensitivity in germanium-doped silica fibres was discovered by observing the formation of Bragg gratings in fibres exposed to intense blue light at 488nm from an argon ion laser [1]. Subsequently, the origin of the phenomenon [2] was linked to the presence of an absorption band near 242nm occurring in oxygen deficient germania glass [3] through the two-photon dependence of the induced refractive index changes [4]. Later, highly efficient grating writing techniques were developed using in-band bleaching with ultraviolet light [2, 5]. A widely used interpretation for the photosensitive effect consists of the photogenesis of carriers by bleaching of the 242nm band, with subsequent trapping of the carriers at different defect sites, thereby changing the ultraviolet absorption spectrum [6]. Refractive index changes are associated with these absorption changes through Kramers-Kronig causality. Apart from using special fibres with a higher germanium concentration, it was discovered that the process could be enhanced by flame brushing [7], or by low temperature hydrogen loading [8].

More recently, new experiments have shown different photosensitive mechanisms in which ArF excimer laser light with a wavelength of 193nm is used to induce refractive index changes in doped silica fibres and waveguides [9, 10]. In these cases, carriers are photogenerated by absorption in the tail of a band located near 185nm which is also associated with oxygen deficient bonds [3, 10]. In this Letter, we report yet another type of photosensitive process for untreated silica fibres with a small germanium dopant concentration, such as Corning SMF-28 telecommunication fibre. Because the linear absorption at 193nm is small in this fibre, a very efficient nonlinear process is possible, leading to refractive index modulations reaching 10⁻⁴ in untreated fibre. This value represents an improvement of one order of magnitude over reported results for this fibre (in the absence of sensitising treatment) [7].

A Lumonics excimer laser filled with an ArF gas mixture and operating at 50 pulse/s with a fluence per pulse of 60mJ/cm² was used in the experiments. A focusing system was used to vary the fluence incident on the fibre between 230 and 1200mJ/cm². Bragg gratings were imprinted in SMF-28 fibres with a zero-order-null phase mask [5], and the reflectivity of the gratings was monitored in real time during the exposure. The time evolution of the refractive index modulation calculated from the reflectivity is plotted in Fig. 1 for four different writing fluences. With this mask, the maximum index modulation achieved is 9.1 x 10⁻⁴. Furthermore, we have verified through microscopic observation and the evaluation of short wavelength loss to cladding modes that the index modulation obtained is definitely of type I, i.e., a uniform refractive index increase across the fibre core, and not type II which implies a damage mechanism at the core-cladding interface exposed to the incoming light beam [11].

![Fig. 1 Growth of refractive index modulation against writing time for Bragg grating resonant at 1.55um in SMF-28 fibre using ArF excimer laser operating at 50 pulse/s](image)

Fluence per pulse incident on the fibre

- 198 mJ/cm²
- 354 mJ/cm²
- 480 mJ/cm²
- 600 mJ/cm²

The origin of this large photosensitive effect may be clarified by plotting the growth rate of the refractive index modulation in terms of the writing fluence. If the refractive index modulation Δn increases as CPf (where C is a constant, f is the fluence and t is the writing time), then the growth rate dΔn/dt is proportional to P. Fig. 2 shows the initial growth rate, calculated from the time required to reach an index modulation of 1.7 x 10⁻⁴, and a power