fields, either the shielding field or the ionisation field. When \( r_{\text{sh}} = 0 \) pm, \( r_{\text{ion}} \) maintained the same value, \( r_{\text{ion}} \approx 5\times 10^{-6} E_{\text{ion}} \). When \( r_{\text{sh}} \) increased from zero, \( r_{\text{ion}} \) results from the competition between \( E_{\text{ion}} \) and \( E_{\text{sh}} \). This competition process is linear. \( \chi^{(2)} \) of the fibre core was the same during the prolonged negative thermal poling but still larger than that of the fibre before poling. The ratio between the two \( \chi^{(2)} \)'s is \(-1.8\).

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References

Gain saturation in silica-fibre Raman amplifier

S.A.E. Lewis, S.V. Chernikov and J.R. Taylor

Measurements of the gain and noise figure properties of a silica-fibre Raman amplifier operating at a central wavelength of 1555nm are reported. Saturation of the gain is observed to occur for input powers exceeding 2dBm in an amplifier with 20dB small signal gain. An increase in the optical noise figure with input power by up to 0.5dB was measured. Output powers of up to 1.4W and 75% internal pump to signal conversion efficiencies are demonstrated.

Introduction: Fibre Raman amplifiers can provide optical amplification and high output powers over a wide range of wavelengths [1 - 4]. We report measurements of the saturated gain and noise figure (NF) of a silica-fibre Raman amplifier (FRA) and compare them with the results of numerical simulations. The single stage amplifier was pumped at a wavelength of 1455nm by a ytterbium-based cascaded-Raman fibre laser [5].

Gain saturation in an FRA is the result of depletion of the pump light by power transfer to the signal. The low loss of this type of amplifier means that the saturated output power is of the order of the pump power. Measurements of the gain and noise figure were made using both CW and modulated signals (for the high output power measurements) using an optical spectrum analyser. The noise figure was calculated using the spectral division method and therefore does not include the relative intensity noise on the signal. Simulations were based on a photon number treatment of the amplifier which included the effects of multipath interference, amplifier self-saturation and saturation by the signal. The fibre parameters were independently measured.

Experiment: The Raman amplifier consisted of a single stage gain fibre pumped at a wavelength of 1455nm by a fibre Raman laser. Pump lasers delivering a maximum power of 3.5W with a spectral width of 1.3nm were employed. Optical circulators were used to multiplex and demultiplex the pump and signal which counter-propagate in the gain fibre. A counter-propagating scheme averages out high frequency intensity and polarisation variations of the pump. Amplification took place in either a 9 or 10km dispersion shifted gain fibre. The peak small signal gain of this amplifier was 35dB at a pump power of 1.7W with a 3dB gain bandwidth of 20nm centred at 1550nm. Further details can be found in [2].

The CW signal source consisted of a DFB laser operating at 1547nm with a 50MHz amplitude modulation to broaden the laser linewidth above the SBS threshold. This was amplified in an erbium doped fibre amplifier (EDFA) to a power of 23dBm and filtered using two tunable bandpass filters (TBPF) (full spectral widths at half maximum of 2.5 and 0.7nm, respectively) in order to remove ASE from the signal. A variable optical attenuator was used to set the signal power. Measurement of the gain and noise figure dynamics shown in Fig. 1 was made using this source and an optical spectrum analyser. The noise figure was calculated using the spectral division method. A 9km dispersion-shifted gain fibre was used in this case.

To modulate the 1562nm CW output of a tunable semiconductor laser a sinusoidally-driven electroabsorption modulator [6] was used. It operated at a repetition rate of 10GHz. The resulting signal was amplified in an EDFA before propagating through 150m of dispersion compensating fibre to remove the frequency chirp from the pulses. A 2.5nm TBPF was used to filter the signal before amplification in a second EDFA which was followed by the output variable attenuator. The transform-limited optical pulses which resulted had a duration of 8ps (assuming a sech² pulse profile). High power performance of the 10km amplifier was investigated using this signal source. Gain measurements were made using an optical spectrum analyser with an input attenuation of 20dB and an optical power meter.

Results: CW measurements of the gain and noise figure at pump powers of 1.55, 1.25, 1.07 and 0.85W are shown in Fig. 1 as scatter points. Continuous lines denote simulation results. Experimentally it is observed that the input power at which 3dB gain compression occurs decreases with pump power: see Table 1.
Table 1: Experimental results

<table>
<thead>
<tr>
<th>Pump power in fibre (W)</th>
<th>Small signal gain (dB)</th>
<th>Saturation input power (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.85</td>
<td>15.7</td>
<td>7.5</td>
</tr>
<tr>
<td>1.07</td>
<td>20.8</td>
<td>2.0</td>
</tr>
<tr>
<td>1.25</td>
<td>24.5</td>
<td>-1.0</td>
</tr>
</tbody>
</table>

This decrease is a result of the exponential dependence of the gain on the pump power. At the highest pump power there was already some gain compression at -15dBm input power as can be seen from the slope of the points at this power level. Higher saturation powers can be achieved by the use of shorter gain fibre and increased pump power. Simulations show that by using a pump power of 2.8W and a 2.6km gain fibre, an increase of 6dB in the saturation input power is achievable in an amplifier giving 20dB small signal gain.

The noise figure of the amplifier with 3dB saturation input powers exceeding 2dBm for an amplifier with 20dB small signal gain.

**References**


**Grating writing through fibre coating at 244 and 248nm**

L. Chao, L. Reekie and M. Ibsen

High quality fibre Bragg gratings have been written through the fibre coating using both 244nm frequency-doubled Ar-ion and 248nm KrF excimer lasers for the first time. A standard off-the-shelf coating was used, and 92% reflection gratings were obtained with an index change of 2x10^-4.

**Introduction:** Fibre Bragg gratings are widely used in the fields of optical fibre communication and fibre sensor systems. In the normal process of fibre grating fabrication, all coatings must be stripped off and the fibre cleaned thoroughly before the grating can be written and, in order to preserve the mechanical strength of the fibre, it must be recoated soon after the grating is manufactured. This procedure is both time consuming and has the potential for reducing the fibre strength due to exposure of the bare fibre to air. To solve the problem, a number of solutions have been proposed. These include using a specially developed UV-transparent polymer coating [1], writing the grating using near UV light around 330nm instead of at more conventional wavelengths [2], writing on-line as the fibre is being pulled [3] and using a specially developed coating which can be removed thermally prior to grating inscription then immediately recoating in an automated production system [4].

The polymer used in [1], although it has a lower absorption than the normal UV-curable polymer coating, still has strong absorption below 260nm. This increases the grating writing time and reduces the mechanical strength of the fibre when higher UV exposure is used [5]. In [2], a specially developed phase mask is needed in order to operate at the non-standard wavelength, together with an increased exposure time due to the reduced UV absorption. In addition, care is also required to control the average laser power in order to reduce damage to the coating.