

An amplitude-modulated, spectrally-optimised Er³⁺ fibre ASE source for use with optical fibre sensors – an example optimised for acetylene gas sensing

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ABSTRACT

We describe a compact, pulsed, broadband source for sensing using ASE from Er³⁺ doped fibre driven by an amplitude-modulated pump. Quiescent pumping halved rise time. The spectrum could be tailored with reflective fibre filters, eg. for C₂H₂ gas detection.

INTRODUCTION

Broadband ASE light from fluorescent or super-fluorescent rare-earth-doped optical fibres is attractive for many optical sensor applications, particularly when single-mode fibre is used for the remote link, or in the sensor itself. We describe such a source, pumped by an amplitude-modulated laser, and optimise it for broadband measurements, in our case, for spectroscopic determination of C₂H₂ gas concentration. We desired a single-mode-fibre-compatible source, with spectral output matched to the 1510 → 1544 nm overtone absorption band of C₂H₂. We also wished to amplitude modulate the source, so a source-pair could be complementary-modulated and used to make measurements using correlation spectroscopy [1]. Of course, many other physical or chemical optical sensors require a source with either amplitude modulation or with a specific spectral output, or with both, so its applications are more general.

A typical output spectrum from an unmodified Er³⁺-doped-silica-fibre ASE source is shown in Figure 1. The absorption spectrum of C₂H₂ in this region is plotted on the same axes. These show that many narrow gas absorption lines could be interrogated without modification. However, three improvements are desirable:-

- (a) the fluorescent lifetime of Er³⁺ ions is rather long, ~10ms [2], which limits the modulation frequency,
- (b) in the long-wavelength spectral tail, the light output extends beyond the absorption band of C₂H₂, which would both reduce the measurement contrast and give excess photon noise,
- (c) some regions of the C₂H₂ spectrum (1510 nm to 1520 nm) are not illuminated by the Er³⁺ emission.

Problem (a) is important, as the modulation of the source should be as rapid as possible for many sensors. For gas sensors it is desired to reduce susceptibility to slower amplitude changes, for example from dust particles or mechanically-induced intensity modulation (caused e.g. by fibre bending or connector movements) and to increase the s/n ratio, in presence of 1/f noise.

We expected that the response time of the ASE source could be improved by firstly ensuring a low level of quiescent pump power, even when the source is switched ‘off’ and, secondly, by reflecting some ASE back into the doped-fibre section. Both these enhance stimulated light emission processes, so hence a more rapid response to pump power modulation. Applying a weak quiescent pump power ensures excitation of some Er³⁺ ions, even when the source is nominally ‘off’. Then, when the pump power is switched to its ‘on’ level, more of these ions will be excited, so internal optical gain will grow more rapidly, therefore reducing the rise time of the source. Reflecting ASE light back into the doped section should reduce the fall time by promoting faster stimulated-emission decay of states when the source is switched ‘off’. Furthermore, by reflecting appropriately filtered light back into the doped – fibre section, greater output power in the desired band and faster response should be achieved by promoting stimulated emissions. Unfortunately, the final problem (c) was not easily overcome,

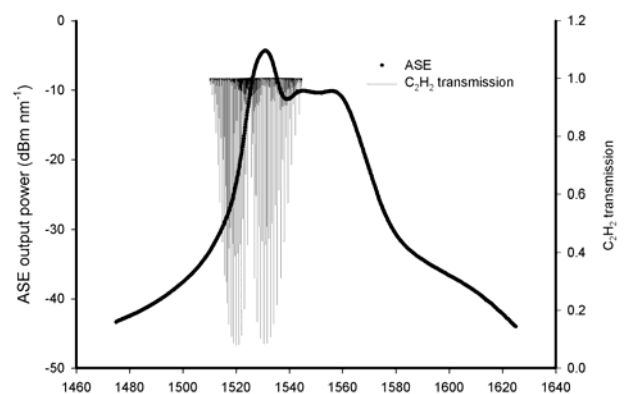


Figure 1 Typical spectral output of Er³⁺ ASE source and transmission spectrum of C₂H₂ gas (taken from [3])

as the Er^{3+} ASE source emitted poorly in this region.

EXPERIMENTAL SETUP AND RESULTS

We have constructed three different test configurations, as set out under the headings below; a simple basic ASE source and two reflective filter configurations, designed to reflect appropriate light of desired wavelength back into the doped-fibre. For each one, we have investigated the switching response of the source, whilst modulating the pump laser diode (980nm) drive current. Pump power was monitored using the internal photodiode within the laser diode package. ASE output power was monitored (via an optical attenuator) using an InGaAs PIN photodiode (Perkin Elmer type C30617) followed by a $1\text{k}\Omega$ transimpedance amplifier.

The three different configurations were:-

Single stage ASE source to investigate source pre-biasing

Figure 2 shows our basic ASE source, where 9 metres of DF 1500L Er^{3+} -doped fibre were coupled to our 980 nm pump diode via a 980/1550 nm WDM. The ASE spectrum, at pump powers of 110 mW and 60mW (at 980nm) is shown in Figure 3. We then square-wave modulated (duty cycle 50%, frequency 200Hz) the pump diode drive current to give various peak pump powers in the 'on' state, and no pump in the 'off' state, resulting in the ASE output waveforms shown in Figure 4. To improve the rise time, we pre-biased the source by applying weak pump currents through the pump diode during the 'off' part of the modulation cycle. Figure 5 shows the resulting ASE output waveforms. The expected decrease in the rise time is clearly visible. We chose a pre-bias pump power of 34.8mW for our further investigation, as at this level there was a significantly reduced output rise time, with only a small penalty in the observed modulation index, resulting in reducing from 100% unbiased, to 97% at our chosen pre-bias level.

By performing appropriate non-linear regressions to fit single exponentials to our data (SigmaPlot 2000), the rise and fall times in unbiased and pre-biased configuration were estimated and are shown in Table 1 (unfiltered column). As expected, the rise-time reduced from $620\mu\text{s}$ to $258\mu\text{s}$, when the 'off' pump power was pre-biased with a power of 34.8mW. However, we found the fall-time actually increased, from $191\mu\text{s}$ to $284\mu\text{s}$, probably because the weak pre-bias pump power continues to promote ions when the source was switched to its 'off' state.

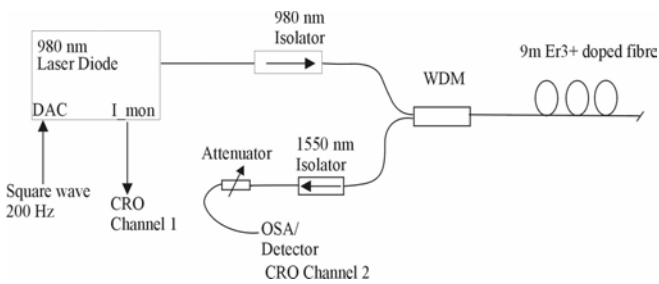


Figure 2 Single-stage Er^{3+} ASE source, with an amplitude modulated pump signal

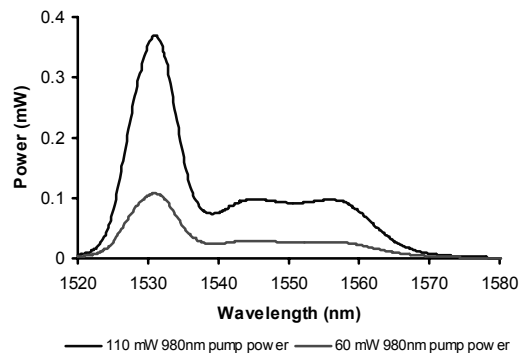


Figure 3 Single-pass ASE source output spectrum, with 9m Er^{3+} -doped-fibre, pump power was 110mW (higher trace) and 60mW (lower trace).

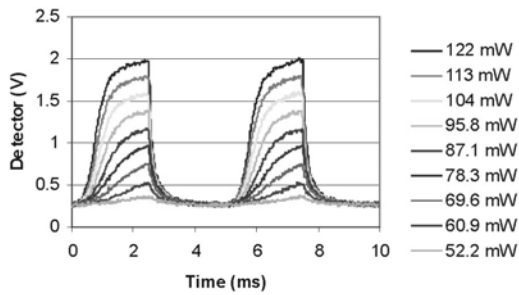


Figure 4 ASE output, while pump power was switched at 200Hz. The pump was switched to the peak power level shown, at a 200Hz rate, with a duty cycle of 50%. Legend is in the same order as the traces.

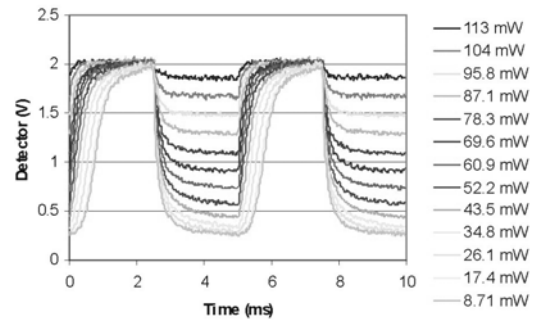


Figure 5 Rise time improvements when pre-biasing with various pump-power levels in the 'off' state. The 'on' pump power was always 122mW, and pre-bias pump powers are shown on the legend in the same order as the traces appear on the graph.

Spectral shaping using dichroic filter

We next added a fibre-coupled dichroic optical filter (passband 1525.9 nm to 1540.1 nm), as shown in Figure 6, to give feedback in a selected optical band. A 980/1550 nm WDM was spliced at the end of the Er³⁺-doped section, to separate ASE and residual pump light. ASE is filtered by the dichroic filter, then light in the passband is reflected by a gold mirror deposited onto the fibre (reflectivity 39%), then filtered a second time, and finally guided back into the doped fibre. A second mirror (reflectivity 37%) reflects unused 980nm pump light back into the doped fibre. The resulting ASE spectrum is shown in Figure 7. As expected, the ASE source spectrum is enhanced at 1540 nm compared to the unfiltered ASE as light at this wavelength is selectively reflected back into the doped-fibre length, promoting stimulated emission and spectrally shaping the ASE source to better suit our needs.

The ASE output power was then switched by modulating the pump laser diode current as before. The waveforms gained were very similar to those gained from unfiltered ASE, so are not reproduced here. The rise and fall times, estimated by non-linear regressions on the collected data are shown in Table 1 (dichroic filter column).

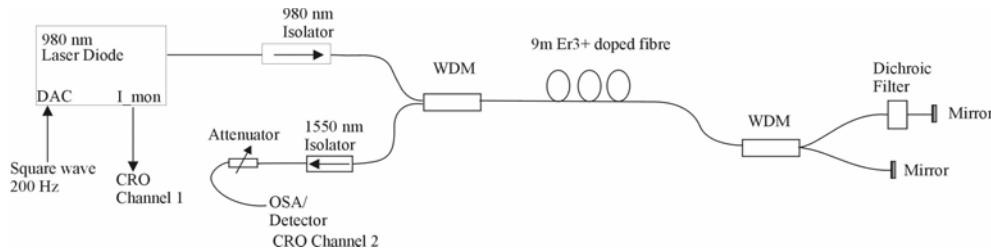


Figure 6 ASE source with reflective (dichroic) filter

Table 1 Rise and fall times of our ASE sources. The pre-biasing power was 34.8mW.

	Unfiltered		Dichroic filter		Chirped fibre grating	
	Rise time (μ s)	Fall time (μ s)	Rise time (μ s)	Fall time (μ s)	Rise time (μ s)	Fall time (μ s)
Unbiased	620 ± 0.4	191 ± 0.7	633 ± 0.6	175 ± 1.2	632 ± 1	227 ± 1
Pre-biased (34.8mW)	258 ± 7	284 ± 0.6	283 ± 1.5	240 ± 0.5	295 ± 2	223 ± 0.4

Spectral shaping using chirped fibre grating

A wide bandpass (reflective from 1522 nm to 1544 nm) chirped fibre grating (kindly fabricated at Aston University) was added, as shown in Figure 9. The resulting ASE output spectrum is shown in Figure 8. The peak we observe at 1544nm shows strong stimulated emission. We modulated the pump drive current and processed the results as before, to obtain the rise and fall times shown in Table 1.

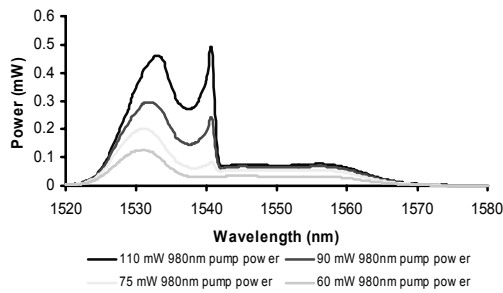


Figure 7 ASE output spectrum with reflective (dichroic) filter.

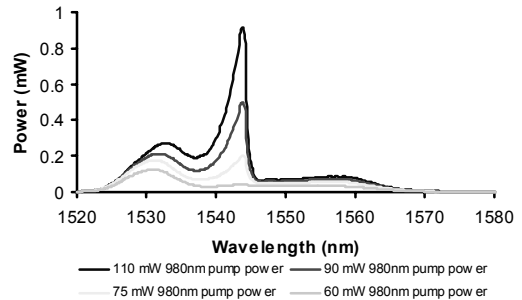


Figure 8 ASE output spectrum with reflective filter using chirped grating.

Spectral shaping using chirped fibre grating

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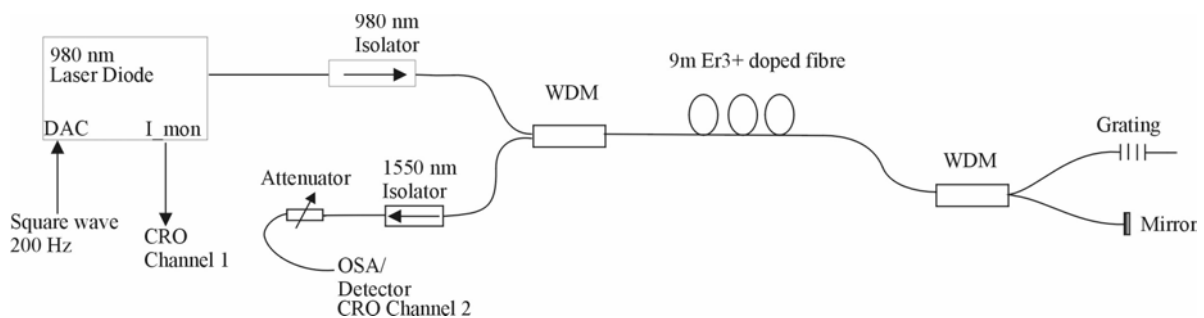


Figure 9 ASE source with reflective filter using chirped grating.

CONCLUSIONS

We have shown that the rise time of our Er³⁺-doped fibre ASE source, with a square wave- modulated pump power, can be significantly improved (620 μ s to 258 μ s), simply by maintaining a small pump power during the ‘off’ part of the modulation cycle. This change gives only a small reduction in modulation index (from 100% peak, when unbiased, 122mW peak pump power, to 97% peak with when ‘off’ pre-bias pump power of 34.8mW was used). Secondly, we have shown that the output spectrum from the ASE source can be tailored to specific needs, by selectively reflecting desired wavelengths of light back into the doped-fibre section, thereby promoting stimulated emission at these wavelengths. Using these methods we successfully optimised our source for broadband C₂H₂ measurements. Clearly the method has potential for many other sensors.

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