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Double Pass Gain in Helium-Xenon Discharges in Hollow Optical Fibres at 3.5 µm

A.L. Love[1*], **S.A. Bateman**[1], **W. Belardi**[1†], **C.E. Webb**[2], **W.J. Wadsworth**[1]
[1]*Centre for Photonics and Photonic Materials, Department of Physics, University of Bath, Bath, BA2 7AY, UK*
[2]*Department of Physics, University of Oxford, Clarendon Laboratory, Parks Rd., Oxford, OX1 3PU, UK*
[†]*Now at the Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK*
[*]*A.Love@Bath.ac.uk*

Abstract: Gain is observed in a double pass of a Helium-Xenon gas DC discharge in a 90cm long flexible hollow core fibre. Output at 3.5µm increases with discharge current up to the maximum of 0.55mA.

OCIS codes: 060.2390 Fiber optics, Infrared; 060.3510 Lasers, fiber; 140.1340 Atomic gas lasers.

Electrically pumped gas discharge lasers have exploited the abundance of laser lines in atomic and molecular gases to produce sources at a wide range of wavelengths from the UV to the infrared. It has been shown that when using a neutral noble gas as a medium, narrower bore tubes can produce more gain and output power [1, 2]. However, as conventional gas discharge tubes require to light to propagate as a free space beam, the dimensions of the tube have been limited by Gaussian beam optics to around 1 mm in diameter. One attempt to overcome these limits was to use specially straightened sub-mm capillary waveguides [1]. While these were effective, they are still dimensionally limited as the waveguide loss scales with r^{-3} and they are extremely bend sensitive, restricting the tubes to diameters greater than 250 µm and lengths of 5–30 cm. For this reason gas lasers still had the image of requiring long, rigorously straight glass tubes, that is until recent development of low-loss hollow core optical fibre technology [3] opened up the possibility of having a flexible gas discharge laser, capable of having a very narrow discharge tube without any fundamental limits on length besides the voltages required to sustain the discharge. The narrower tube diameters have however made the discharge parametres much harder to achieve. While several groups have attempted to create discharges in very narrow bore capillaries and fibres with a variety of methods including DC, RF and microwave coupled discharges [4, 5], recent breakthroughs were made in creating DC-excited glow discharges in fibres over 1 m in length [6]. Using a mixture of HeXe, strong indications of gain on the three xenon transitions of 3.11 µm, 3.37 µm and 3.51 µm were observed over a variety of fibre lengths. Here we continue with that work with a double pass experiment with these discharges, as a step towards a full laser cavity.

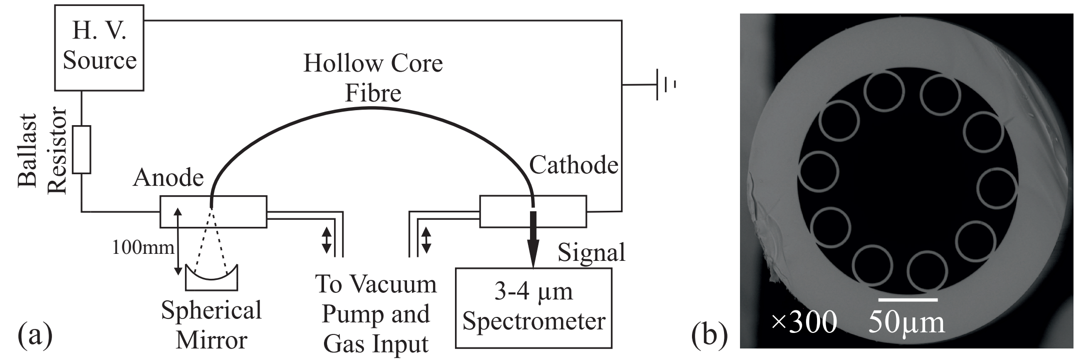

Fig. 1. (a) Experimental setup. (b) SEM image of the fibre.

The system shown in Fig. 1 (a) was used to produce and sustain DC glow discharges within a 90 cm long hollow core optical fibre. The ends of the fibre were held inside a pair of gas cells for the evacuation and delivery of gas to the system, inside which a pair of electrodes were positioned near the fibre ends to deliver a DC high voltage of up to

40 kV with a variable current. The anode gas cell featured a large calcium fluoride window perpendicular to the fibre. The fibre used (Fig. 1 (b)) had a hollow core inner diameter of approximately 120 µm, and a low loss guidance band from 3–4 µm (< 0.18 dB/m at 3.5 µm). This type of fibre has a low bend loss of ~ 0.3 dB per turn of radius 8 cm [7]. The spectrometer (*Bentham DTMc300*) had a grating with 300 grooves/mm and a cryogenically cooled InSb detector for the range at 3–4 µm.

Discharges were performed with a 5 : 1 mixture of HeXe at a total pressure of 12 mbar which produced a strong emission at the 3.51 µm transition. By positioning a 100 mm radius of curvature circular mirror at the anode end of the fibre, light was reflected back into the fibre to perform a double pass. Assuming that the amount of light coming out of each end of the fibre is equal and that the coupling efficiency between the mirror and the fibre is 100%, then in the absence of gain the best possible increase of signal in the double pass is a factor of two. Fig. 2 (a) shows the signal for a single and double pass against the discharge current normalised to the signal from a single pass with a current of 0.2 mA. These were recorded by covering and uncovering the mirror while stepping the current up then down for the same discharge. From this is it clear that the factor difference between the single and double passes is greater than two, at its highest reaching a factor of 2.6, which indicates gain as the actual coupling efficiency will be considerably less than 100%. The small increase is also an indication that the system may be close to saturation by amplified stimulated emission even from a single pass. Fig. 2 (b) shows the emission spectrum of a single and double pass for a single discharge at a current of 0.25 mA, which shows no noticeable increase in signal on the 3.11 µm and 3.37 µm emission lines, showing a gain on the 3.51 µm line and not on any of the other emission lines.

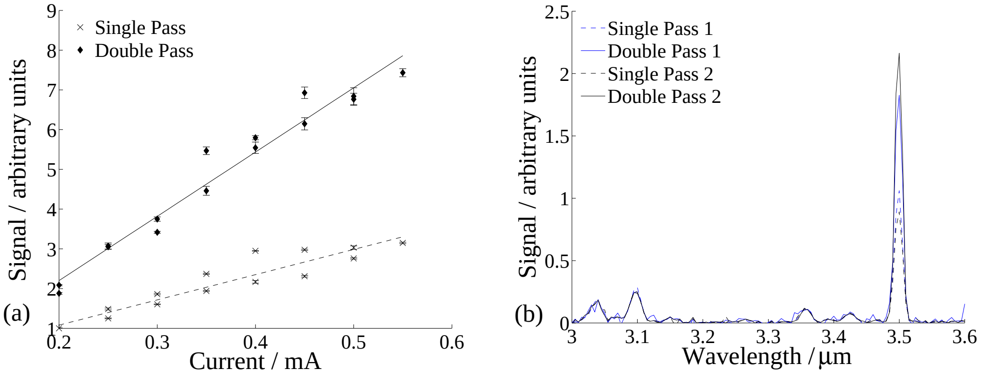

Fig. 2. (a) Signal at various currents for single (dashed) and double (solid) pass discharges in 90 cm of fibre. (b) Spectra for single (dashed) and double (solid) pass discharges in 90 cm of fibre with a discharge current of 0.25 mA and 20 nm resolution.

We have shown gain in the 3.51 µm Xe transition in HC-PCF gas discharges by performing a double pass experiment, and in doing so we have demonstrated that it is possible to couple light from these discharges back into the fibre for an electrically excited fibre-based gas laser.

References

[1] P.W. Smith, “A waveguide gas laser,” Applied Physics Letters, **19**, 132 (1971)

[2] D. Schuöcker, W. Reif and H. Lagger, “Theoretical Description of Discharge Plasma and Calculation of Maximum Output Intensity of He-Ne Waveguide Lasers as a Function of Discharge Tube Radius,” IEEE J. Quantum Electronics, **QE-15**, 232 (1979)

[3] F. Yu, W. Wadsworth and J. C. Knight, “Low loss silica hollow core fibres for 3–4 µm spectral region,” Optics Express, **20**, 11153, (2012)

[4] X. Shi *et al*, “Investigation of glow discharge of gas in hollow-core fibres,” Appl. Phys. B, **91**, 377 (2008)

[5] B. Debord *et al.*, “Generation and confinement of microwave gas-plasma in photonic dielectric microstructure,” Opt. Express, **21**, 25509 (2013)

[6] S. A. Bateman *et al.*, “Gain from helium-xenon discharge in hollow optical fibres at 3 to 3.5 µm,” in *CLEO: Science and Innovations*, (Optical Society of America, San Jose, USA, 2014), paper STh5C.10

[7] W. Belardi and J.C. Knight, “Hollow antiresonant fibres with low bending loss,” Opt. Express, **22**, 10091 (2014)