Synchronously Pumped Mid-IR Hollow Core Fiber Gas Laser

M. R. Abu Hassan[1]*, Fei Yu[1], Zefeng Wang[1,2], Walter Belardi[1], William J. Wadsworth[1] and Jonathan C. Knight[1]

[1]*Centre for Photonics and Photonic Materials, Department of Physics, University of Bath, Bath, BA2 7AY, UK.*
[2]*College of Optoelectronic Science and Engineering, National University of Defense Technology, Changsha, 410073, China*
**mrah20@bath.ac.uk*

Abstract: We report a synchronously pumped 3.16 μm acetylene fiber laser based entirely on low-loss silica hollow-core fiber. Our system oscillates at 2.568 MHz repetition rate, when pumped with a modulated amplified 1.53 μm diode laser.

OCIS codes: (060.4005) Microstructured fibers; (140.3070) Infrared and far-infrared lasers; (140.4130) Molecular gas lasers.

1. Introduction

Fiber lasers based on rare-earth-doped silica are very successful out to around 2.2 μm wavelength. They fail at longer wavelengths because of the increasing optical absorption of silica. Competing fiber technologies based on different material systems have great potential but suffer from drawbacks including fiber weakness, low damage threshold, high nonlinearity and high dispersion. The development of the low loss hollow-core fiber (HC-fiber) in the mid-IR region [1] provides an opportunity for efficient fiber gas lasers using HC-fiber. The fiber gas laser combines attractive features of fiber lasers such as compactness and good thermal management with those of gas lasers such as the potential for high output power and narrow line width. In this paper, we demonstrate a synchronously pumped 3.16 μm acetylene-filled hollow core fiber gas laser. Our system uses 12m of acetylene-filled HC-fiber and an additional 101 m of HC-fiber to form a ring cavity, and is synchronously pumped with a tunable 1.53 μm diode laser. We report lasing at 3.16 μm corresponding to the P (9) transition. We describe measurements of the output power as a function of feedback which will enable us to optimize the output coupling.

2. Experimental setup

Previous work [2-4] has shown that single-pass amplified spontaneous emission (ASE) can lead to a measurable output from this transition, but continuous-wave laser operation is not possible because of the fact that the lower laser level cannot spontaneously transit back to the ground state. As a result, the laser emission is self-terminating. We have used the very low attenuation of our hollow fibers (<30 dB/km at the laser wavelength) to delay the pulsed laser output so as to enable the molecules to return to the ground state through collisions with each other and with the fiber core walls. When the delayed pulse is fed back into the gain fiber and it is synchronously pumped this enables pulsed operation of the laser cavity. The acetylene-filled HC-fiber laser cavity configuration is shown in the Fig. 1. The ends of the 12 m long gain fiber are sealed in gas cells; the fiber is evacuated, and then filled with 0.3 mbar of C_2H_2. A pump wavelength of 1530.383 nm from a narrowband tunable diode laser (tuned to an acetylene absorption line) was modulated to 40 ns pulses at a repetition rate of 2.568 MHz, corresponding to the cavity round-trip time. It was then amplified to an average power of 72.3 mW (pulse energy up to 28 nJ) using an EDFA and coupled into the gain fiber through a window. Mid-IR emission from the output end of the gain fiber was coupled into 101 m of low-loss feedback HC-fiber. A dichroic mirror (high transmission at 1.53 μm, high reflection at 3.16 μm) was used to couple the delayed laser pulse back into the gain fiber. We estimate the total feedback loss (including the output coupling) to be -5.9 dB. To make the cavity oscillate, the pump repetition rate must be carefully adjusted (using a Stanford Digital Delay Generator DG645 to control the pump seed modulator) so that the circulating laser pulse is coincident in time with a 1.53 μm pump pulse. About 7% of the total power is coupled out of the cavity using an uncoated CaF_2 window as output coupler, as shown in Fig. 1.

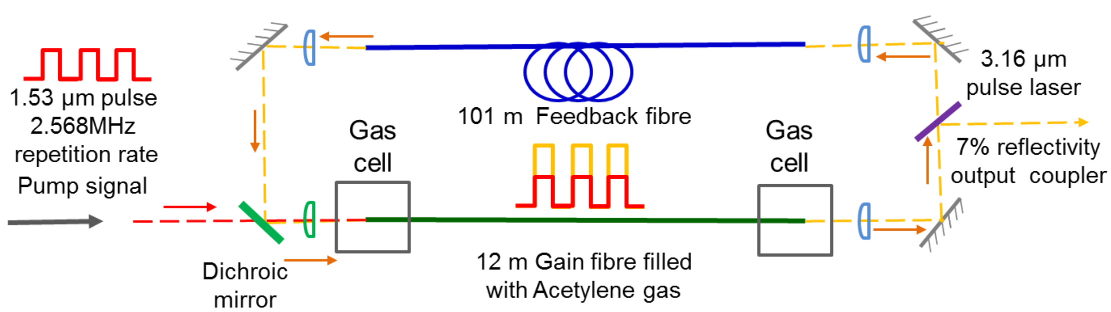

Fig. 1 Schematic diagram of the C_2H_2 gas filled hollow-core fiber laser cavity.

3. Results and discussion

The output spectrum from our laser is shown in Fig 2(a). It shows a single laser line at a wavelength near 3.16 µm. The inset shows the output spectrum reported in [4] of the C_2H_2 filled HC-PCF in the single-pass configuration. The single-pass configuration reported in [2-4] shows two ASE emission lines corresponding to the R (7) and P (9) transitions. In the cavity configuration only one lasing line is observed above threshold near 3.16 µm, corresponding to the P (9) transition. This is to be expected because the two lines share a common upper level, and the presence of a single line above threshold is clear evidence of the effect of feedback in our cavity. Indeed, if we block the feedback in our system no output can be measured, and our pump pulse energies are at least 100 times below those used in [2-4]. In the absence of feedback our pump pulse energies do not produce measureable emissions.

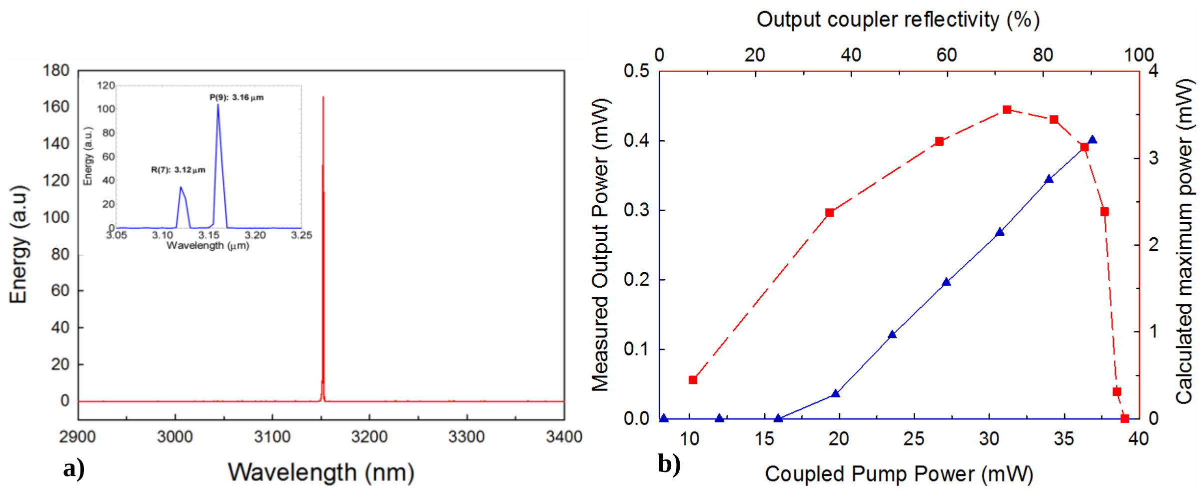

Fig. 2 (a) Measured optical spectrum at 0.3mbar C_2H_2; the inset shows the optical spectrum reported in [4] (recorded at low resolution) showing the presence of two transitions in the ASE mode; (b) Measured output power (blue triangles) measured after output coupler is plotted versus the coupled pump power at 0.3 mbar pressure (lower and left-hand axis); the calculated attainable output (red squares dashed line) is plotted versus output coupler reflectivity (%) (Top and right hand axis).

In the Fig 2(b), the measured laser output power is plotted as a function of the coupled pump power at 0.3 mbar pressure. The laser output power increases linearly with the coupled pump power beyond a threshold pump value. The threshold value of the coupled pump power to obtain a 3.16 µm output is 16 mW. Using the 7% output coupler, the maximum output power is around 0.4 mW. The output power extracted from the cavity could be increased if we optimized the reflectivity of the output coupler. The dashed (red) curve (right hand/top axes) in Fig. 2b shows the potential output power if we vary the reflectivity of the output coupler. This curve is derived from a measurement of the actual output power at a fixed output coupling by inserting a variable attenuator after the output coupler (Fig.1). This curve shows that we can expect to obtain around 3.5 mW output power from our current configuration if we use a 70% output coupler.

4. Conclusions

We have demonstrated a synchronously-pumped 3.16 µm fiber laser based entirely on the use of silica hollow-core fiber and pumped with an amplified 1.53 µm diode laser. The high damage threshold and low nonlinearity of hollow-core fibers suggest that the laser can be scaled to far higher output powers. This scheme can also be adapted using different molecules and transitions to produce output at a range of different wavelengths in the mid-IR.

5. References

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