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Ultrafast Optical Gain Switching for Wavelength Conversion from Silica to Polymer Optical Fibre Communication Wavelengths

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Abstract Optical gain switching is demonstrated for red emission distributed feedback polymer lasers operating close to the 650 nm polymer optical fibre low loss window, namely at 675 and 692 nm. With control pulses (5kHz, 4ps) at telecommunication wavelengths, 1.28 and 1.32 μm the gain switch operates as a wavelength conversion element.

Introduction

Polymers have been increasingly used to fabricate passive structures within tele- and data-communication systems with robustness, ease of processing, integration and low cost among the key drivers [1, 2]. It has also been recognized that such plastic fibre and waveguide structures might benefit from the incorporation of gain, ultrafast optical switching and other active functionalities, with organic semiconductor materials and devices considered particularly promising due to their potential for ready integration [3].

We report here on optical gain switching in polyfluorene-based red light emitting distributed feedback (DFB) lasers using 1.3 μm optical control pulses to directly modulate their output. Given the polymer optical fibre (POF) defined 650 nm centred target wavelength window [4], we selected red emission copolymer Red F [5] as the gain medium and fabricated polymer lasers with lasing wavelength at 675 and 692 nm. The wavelengths of control pulse (5kHz, 4ps) were specially chosen in the telecommunication range, 1.28 and 1.32 μm. We demonstrate the ability to completely shut down the visible laser output in the presence of the control pulses, providing a wavelength conversion scheme to transfer data from silica to polymer optical fibre communication windows. By tuning the temporal overlap of the laser pump and control pulses it is also possible to more subtly control the laser dynamics, for example to introduce a variable time delay as needed for data re-timing.

Experimental

The Red F polymer used in our study was provided by the Sumitomo Chemical Co., Ltd and was used as supplied. The DFB lasers were prepared by spin-coating toluene solutions of Red F (20 mg/ml) onto one-dimensional grating patterned silica substrates. Two grating patterns were used with periods (Λ), fill-factors and depths: (a) Λ = 420 nm, 50% and 100 nm and (b) Λ = 430 nm, 20 % and 50 nm. After coating 240 nm Red F films these structures showed laser action at 675 nm and 692 nm, respectively.

Pump and control pulses were generated by an amplified 5 kHz Ti:sapphire laser pumped optical parametric amplifier. The pulses were stretched to ~ 4 ps (FWHM) in a highly dispersive TF-10 glass block in order to better match the time resolution of the Hamamatsu synchroscan streak camera used as detector (~ 2 ps). The wavelength of the control pulse was tuned from 1.28 to 1.32 μm, which resulted in a slight change of the pump wavelength from 492 to 498 nm. The optical pump and control beams were spatially overlapped on the sample in a spot of 100 μm diameter but subjected to a variable time delay.

Result and Discussion

Figure 2 shows streak camera images in which the output from the frequency doubled 1.28 μm control beam (left side of each image) and the 692 nm Red F DFB laser (right side of each image) are simultaneously detected. The vertical axis represents the time scale 0-100 ps from top to bottom and the horizontal axis represents a wavelength scale 595 – 725 nm from left to right. The Red F laser was pumped with 36 nJ pulses (≈ 1.5 times the lasing threshold energy). The control pulses were adjusted to 2 μJ, an energy that, after frequency doubling, gave a comparable intensity signal on the streak camera to that of the Red F laser. Figure 2(a) shows the situation in the absence of any control pulses and is thus simply the laser beam profile. Turning the control pulses on causes the intensity of the polymer laser output to decrease significantly as shown in Figure 2(b) and when they are suitably synchronised with the DFB laser pump pulses the 692 nm laser emission is completely quenched (Figure 2(c)). The same behaviour was found for the 675 nm Red F DFB

laser and for 1.32 µm control pulses, demonstrating the reproducibility of the phenomenon across a range of DFB laser output and control pulse wavelengths.

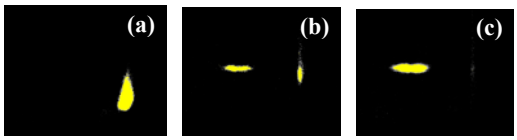

Figure 1 Streak camera images for the 692 nm Red F DFB laser and frequency doubled 1.28 µm control pulses. The control beam is shown as a streak on the left of the images and the Red F laser output appears as a streak on the right of the images. The situations shown are: (a) Control pulses off. (b) Control pulses on but not synchronised to switch the DFB laser fully off. (c) Control pulses on and synchronised to switch the DFB laser off.

By tuning the temporal delay between pump and control pulses and adjusting their relative intensities, we find that gain switching can be achieved under a variety of situations. Figure 2a shows representative changes in the pulse dynamics of the emission from the DFB laser with a weak control pulse. In this case, the Red F DFB laser was pumped at eight times the laser threshold (200 nJ per pulse) and subjected to relatively weak (50 nJ) control pulses adjusted to arrive at the sample at the same time as the pump pulse (not shown). The spectral profiles of the emission from the DFB laser also show that the laser emission was replaced by a broadband PL emission when the control pulses were turned on, demonstrating that under suitable conditions, even a relatively weak control pulse can switch the laser off.

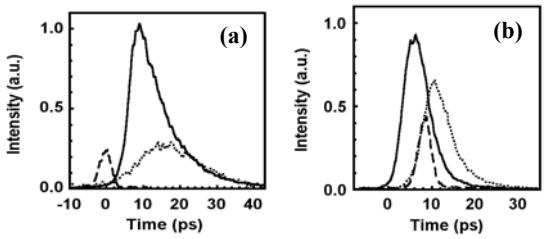

Figure 2 Temporal profile of the second harmonic of the control pulse and the DFB laser output simultaneously detected by the streak camera. (a) a strongly pumped (200 nJ pulses) Red F laser modulated by weak (50 nJ) 1.28 µm control pulse timed to arrive at the same time as the pump pulse (i.e. in advance of the DFB laser emission). (b) a 675 nm Red F DFB laser (pumped with 80 nJ pulses) modulated by intense (200 nJ) 1.32 µm control pulses which were timed to arrive 3 ps (peak-to-peak) after the unperturbed DFB laser output. The dashed lines are the second harmonic of the control pulse. The solid lines are the DFB laser output in the absence of any control pulses whilst the dotted lines are the emission output with the control pulse turned on.

A more subtle control of the DFB laser emission is also possible, allowing adjustment of the output pulse intensity, temporal profile, and time delay relative to the pump pulse. The latter delay offers the potential for data re-timing, another important function in communication systems. Figure 2b shows just such a temporal shift in the polymer laser output due to control pulses that are synchronized to arrive at the sample after the onset of lasing. The 675 nm DFB laser was pumped at 498 nm with 80 nJ pulses (i.e. four times threshold) and its output was modulated with a 200 nJ control pulse at 1.32 µm, delayed by 3 ps (peak-to-peak) relative to the unperturbed polymer laser output. The polymer laser output pulse was delayed by some 5 ps as an effect of the control pulse but there was very little change in temporal width. In this case, the spectral content was also little altered but there was an approximately 35% drop in pulse intensity. These data are representative of a very large parameter space in regard of relative pump and control pulse intensities and time delays and are, as such, only indicative of the response that can be induced.

Conclusion

We have demonstrated optical gain switching in polyfluorene-based red light emitting distributed feedback (DFB) lasers using 1.3 µm optical control pulses (4 ps, 5 kHz) to directly modulate their output. These results suggest the potential to use ultrafast all-optical gain switching for wavelength conversion between the silica-fibre telecom and plastic-fibre datacom windows in such polymer devices.

Acknowledge

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