Enhanced tuning mechanism in fibre laser based on multimode interference effects

G. Anzueto-Sánchez, A. Martínez-Ríos, D. A. May-Arrioja, I. Torres-Gómez, R. Selvas-Aguilar and J. Álvárez-Chávez

A 12 nm tunable fibre laser is demonstrated. The tuning mechanism uses an SU-8 fibre gripper for automatic alignment of a multimode fibre and gold-coated fibre (facet) mirror. Wavelength tuning is achieved using the wavelength dependent re-imaging effect that occurs in multimode fibres.

Introduction: Basic spectroscopy features, such as wide gain and broad absorption bands, make rare-earth doped fibres very attractive as an active medium to develop versatile tunable lasers [1]. In double-clad fibres, the ability to provide broadband wavelength tuning and high output power results in devices with unique characteristics. The tuning range is mainly determined by the broadband high reflective mirrors of the cavity, the gain medium, and, in particular, the tuning mechanism. Some double-clad fibre lasers are tuned by external elements such as bulk gratings, which require complicated arrangements and lead to an expensive device. Another option is the use of fibre Bragg gratings. However, this latter option typically requires complex and expensive electronic controlling elements [2].

In a recent work [3], we demonstrated wavelength tuning for fibre lasers based on the re-imaging effect that takes place in multimode waveguides. In that case, the wavelength tuning device consisted of a 15 mm-long multimode fibre (MMF) with one end spliced to a singlemode fibre (SMF), while the other end was physically separated from a 1-inch broadband metallic mirror. By varying this separation it is possible to tune to the desired lasing wavelength. Using this approach, a tuning range up to 8 nm was measured in an ytterbium-doped fibre laser, with the tuning range limited primarily by the spectral response of the mirror, and the mechanical alignment of the MMF and the mirror arrangement. Therefore, further refinement of the tuning mechanism is required in order to maximise the tuning range that could be obtained with this device.

In this Letter we present a novel and an enhanced design for the wavelength tuning mechanism in a fibre laser. For this purpose, an SU-8 fibre gripper structure was fabricated that automatically aligns the MMF and a gold-coated fibre (facet) that acts as a fibre mirror. The relative separation between the fibre mirror and the MMF is also controlled by a micrometric stepping motor. These improvements, in combination with the flat infrared (IR) spectral characteristics of the fibre mirror, resulted in a tuning range of 12.24 nm (1083.42 to 1095.66 nm) for a double-clad ytterbium-doped fibre laser. Numerical simulations are also included to corroborate our experimental results.

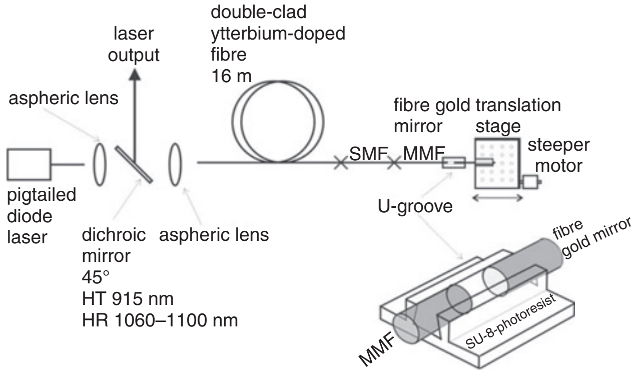

Fig. 1 *Schematic diagram of experimental setup*

Inset: Enhanced wavelength tuning device

Tuning apparatus: Fig. 1 (inset) shows a schematic of the wavelength tuning device. It consists of an SU-8 fibre gripper which is essentially a channel with negative slope walls. The structure is designed such that when a fibre is inserted in the groove it will be held within the channel. This provides automatic x-y alignment of two fibres while still allowing their movement along their longitudinal direction. The fabrication process of the SU-8 structures is well explained in [4]. In our case, one fibre corresponds to the MMF and the other to the fibre mirror. The fibre mirrors were fabricated on standard singlemode fibres by coating one facet with a gold film using a standard thermal evaporator. Therefore, the MMF was fixed to the SU-8 structure, while the fibre mirror was attached to a computer-controlled micrometric stepping motor to obtain accurate control of the longitudinal displacement of the fibre mirror. This tuning mechanism resulted in a very compact and stable device that provides an extremely simple method to control the emission wavelength of the ytterbium-doped fibre laser.

Light is launched into the MMF using a standard SMF. The length of the MMF is selected so that an image of the initial singlemode input is obtained at a free-space point outside of the MMF. The field that propagates through free space is expressed as [5]

$$E_{\mathrm{out}}(r, L_{MMF} + z_{\mathrm{out}}) = \sum_{m=1}^{21} c_{0,m} J_0\left(u_{0,m}\frac{r}{a}\right) \times \exp[-i(\beta_{0,m}L_{MMF} + \beta_{\mathrm{out},m}z_{\mathrm{out}})] \qquad (1)$$

where $c_{0,m}$, $u_{0,m}$, $\beta_{0,m}$, $\beta_{\mathrm{out},m}$ are the field excitation constant, the transverse propagation constant inside the core, the longitudinal propagation constant, and the longitudinal propagation constant at free space for the mth mode, respectively. Here, L_{MMF} is the length of the MMF, a is the core diameter of the MMF, and z_{out} is the separation distance between the MMF and the fibre mirror. It is assumed that only 21 radial modes contribute to the summation in (1), i.e. $M = 21$, as can be obtained by solving the eigenvalue equation for the transverse propagation constants. The inset of Fig. 2 shows the resultant intensity distribution obtained with a finite difference beam propagation method (FD-BPM). The intensity distribution is shown along 245 μm in the MMF from the input facet of the SMF, for two different wavelengths, 1080 and 1087 nm. Here we have assumed that the fibre mirror is separated from the MMF facet by 180 μm, and the total length of the MMF is 13.945 mm. For better appreciation, in the graphs we have plotted only the first 245 μm of the MMF. As can be observed in the inset of Fig. 2, we expect a better coupling into the SMF for the 1080 nm wavelength with this 180 μm separation distance. The power that is coupled back from the MMF into the SMF can be calculated by evaluating the overlap integral of equation (6) in [5]. We calculated the relative contribution at each wavelength by assuming a mirror reflectivity of 100%. This is shown in Fig. 2, where we estimated the power coupled into the SMF against MMF-mirror separation for four different wavelengths. As can be observed, at a given MMF-mirror separation there is a wavelength that experiences the maximum coupling into the SMF.

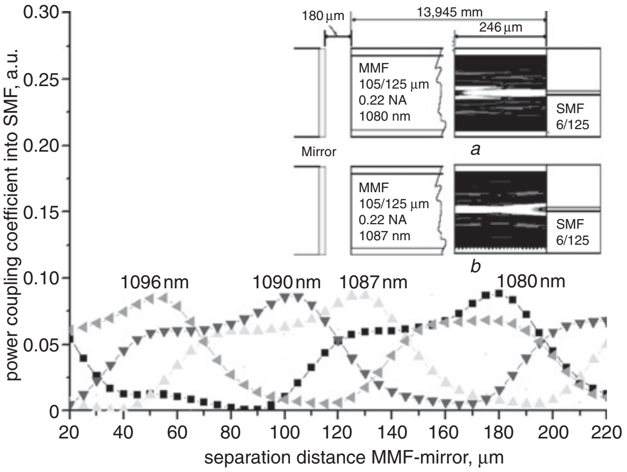

Fig. 2 *Numerical simulation of power coupling coefficient between MMF into SMF for four different wavelengths*

Inset: Numerical simulations of intensity distribution along 240 μm in MMF from SMF
a 1080 nm
b 1087 nm

Experimental setup and results: The experimental setup is shown in Fig. 1. It consists of a double-clad ytterbium-doped fibre (DCYDF). The DCYDF is end-pumped by a fibre pigtailed multimode laser diode coupled to the DCYDF via two aspheric lenses, with a maximum launched pump power of 1.8 W at a wavelength of 915 nm. Between the two aspheric lenses there is a dichroic mirror with high transmission at the pump wavelength and high reflection from ~1060–1100 nm in order to separate the signal output power. The other end of the fibre was spliced to the tuning device, through the free end of the SMF which serves as the filter for the non-absorbed pump. The laser emission is extracted out of the cavity via the dichroic mirror.

The tunability of the system was characterised by measuring the lasing wavelength against the separation between the MMF and the fibre mirror. The results are shown in Fig. 3. It can be observed that for distances greater than 180 μm no laser emission is obtained. However, when this distance is reduced from 180 to 60 μm, a quasi-linear wavelength tuning is observed with a range of 12.2 nm. This behaviour is consistent with the numerical results, where for shorter distances a longer wavelength is obtained. This is also shown in Fig. 3, where the peak wavelength coupled back to the SMF is plotted for each separation, and a linear response is indeed obtained. Nevertheless, for distances shorter than 60 μm, the tuning response changes drastically, exhibiting a resonant-like behaviour. This effect is related to Fabry-Perot resonances arising from the MMF facet and fibre mirror, which modify the predicted linear response. This issue could be resolved using an antireflection coating on the MMF facet, and should provide a wider tuning range. Regardless of this resonance, a tuning range of 12.24 nm with a slope efficiency around 30% for each wavelength can be easily obtained. This novel tuning device provided an effort-free fibre alignment and a highly stable system since the fibres are held within the channel of the SU-8 fibre gripper. The system is also relatively inexpensive when compared with other tuning techniques.

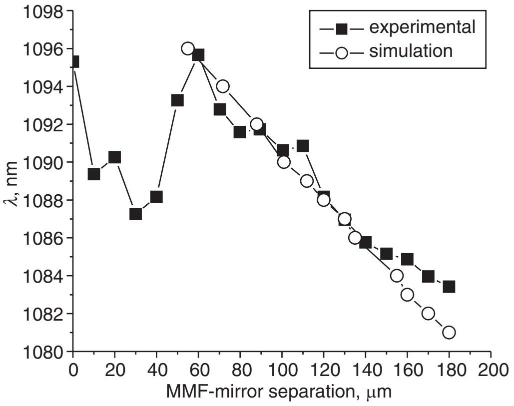

Fig. 3 *Experimental results and numerical results of displacement of facet mirror fibre against emission wavelength*

Conclusions: We have demonstrated an enhanced tuning mechanism in a cladding pumped fibre laser. A novel tuning mechanism was implemented using an SU-8 fibre gripper which provided automatic alignment of an MMF and a fibre mirror. A tunability of 12.24 nm was measured with this implementation, and the laser system was shown to be very robust and highly stable.

29 June 2006
Electronics Letters online no: 20061714
doi: 10.1049/el:20061714

G. Anzueto-Sánchez, A. Martínez-Ríos, I. Torres-Gómez and J. Álvarez-Chávez (*Department of Optical Fiber, Centro de Investigaciones en Optica, Leon, Guanajuato 37170, Mexico*)

E-mail: amr6@cio.mx

D.A. May-Arrioja (*CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL 32816-2700, USA*)

R. Selvas-Aguilar (*Facultad de Ciencias Fisico Matematicas, UANL, San Nicolás de los Garza, NL, 66450, México*)

References

1 Nilsson, J., Clarkson, W.A., Selvas, R., Sahu, J.K., Turner, P.W., Alam, S.U., and Grudinin, A.B.: 'High-power, wavelength tunable, cladding-pumped, rare earth doped fiber laser', *Opt. Fiber Technol.*, 2004, **10**, pp. 5–30
2 Mokhtar, M.R., Goh, C.S., Butler, S.A., Set, S.Y., Kikuchi, K., Richardson, D.J., and Ibsen, M.: 'Fibre Bragg gratings compression-tuned over 110 nm', *Electron. Lett.*, 2003, **39**, (6), pp. 509–511
3 Selvas, R., Torres-Gomez, I., Martinez-Rios, A., Alvarez-Chavez, J., May-Arrioja, D., LiKamWa, P., Mehta, A., and Johnson, E.G.: 'Wavelength tuning of fiber lasers using multimode interference effects', *Opt. Express*, 2005, **13**, pp. 9439–9445
4 Raymond, C., and Johnson, E.G.: 'Micro-photonic systems utilizing SU-8' *in* A. El-Fatatry (Ed.): *Proc. SPIE*, **5346**, 'MOEMS and miniaturized systems IV', 2004, pp. 64–69
5 Mohammed, W., Mehta, A., and Johnson, E.G.: 'Wavelength tunable lens based on multimode interference', *J. Lightwave Technol.*, 2004, **22**, pp. 469–477