

Performance and outlook for isolator-free 2 micron fiber lasers

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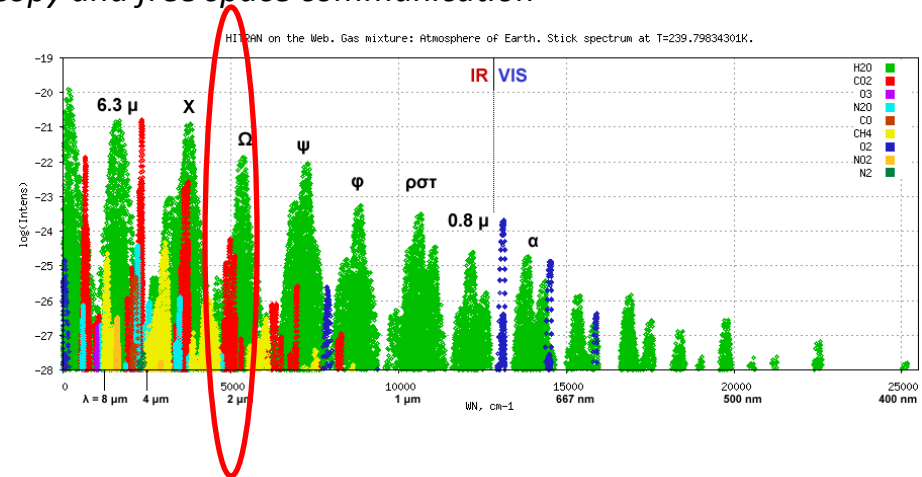
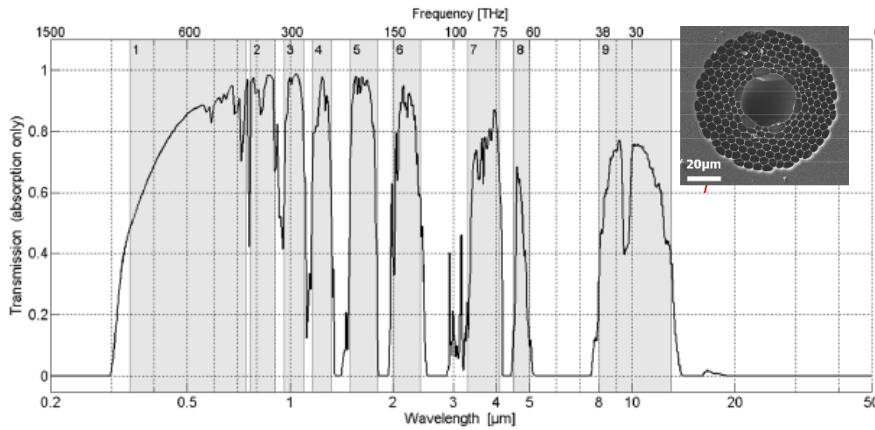
*Supported in part by the Swiss National Science
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Student: Svyatoslav Kharitonov



2 micron radiation

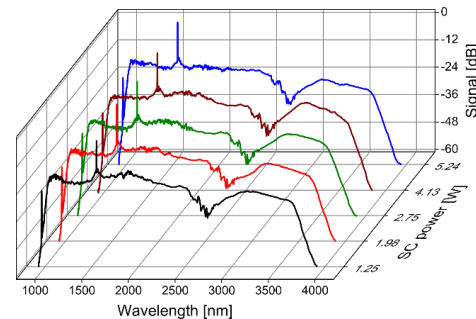
Remote sensing, spectroscopy and free space communication



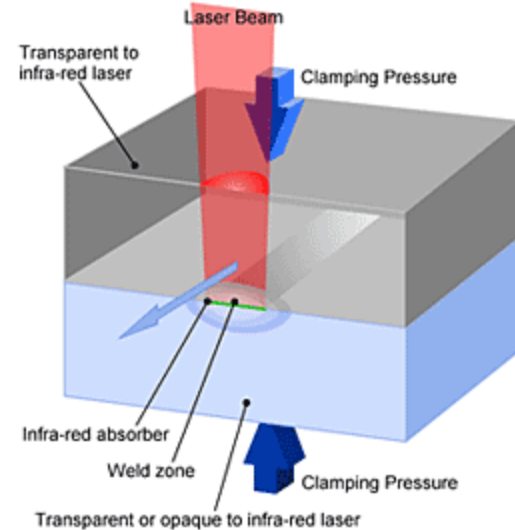
Medical diagnostic \ Surgery

<p>Neurosurgery</p> <ul style="list-style-type: none"> Fenestration of cysts Ventriculocysternotomy 3rd ventriculostomy Tumor resection Haemostasis 	<p>ENT</p> <ul style="list-style-type: none"> Tonsillectomy Stapedectomy Excision of tumors Excision of granulomas UVPP
<p>Pneumology</p> <ul style="list-style-type: none"> Bronchoscopy Airway recanalization Desobstruction Tissue coagulation 	<p>Spinal Surgery</p> <ul style="list-style-type: none"> Laser discectomy Laser foraminoplasty PLDD
<p>Gynaecology</p> <ul style="list-style-type: none"> Excision of polyps Endometriosis Hysterectomy Adhesiolysis Conisation Condylomata Myomectomy 	<p>Urology</p> <ul style="list-style-type: none"> Vaporesection of prostate Vaporisation of prostate Resection of prostate Enucleation of prostate Bladder neck incision Opening of strictures Vaporisation and excision of bladder tumors Partial nephrectomy Laparoscopy Lithotripsy
<p>Arthroscopy</p> <ul style="list-style-type: none"> Capsular shrinkage Cartilage smoothing Miniscectomy Synovectomy 	<p>General Surgery</p> <ul style="list-style-type: none"> Surgery of well circulated organs Tissue vaporization Volume coagulation Haemorrhoids

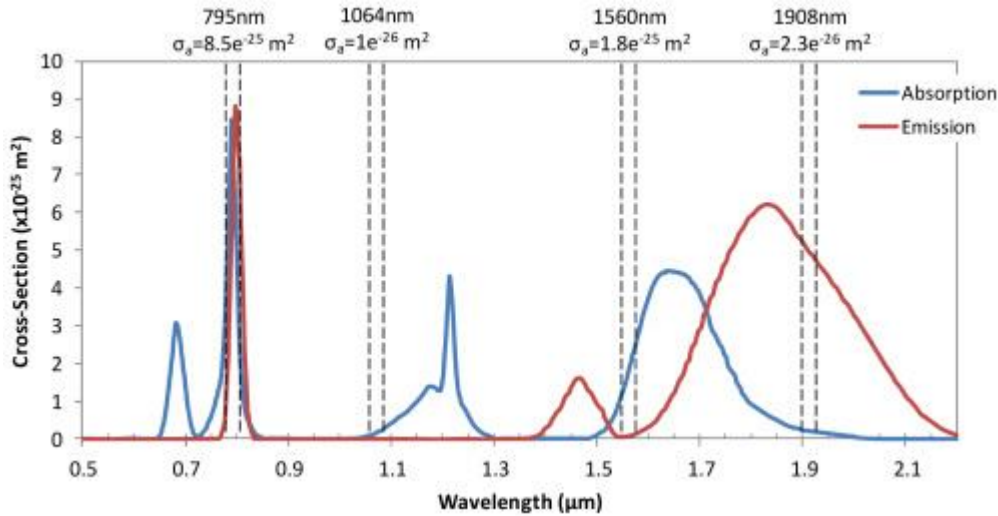
MIR supercontinuum generation



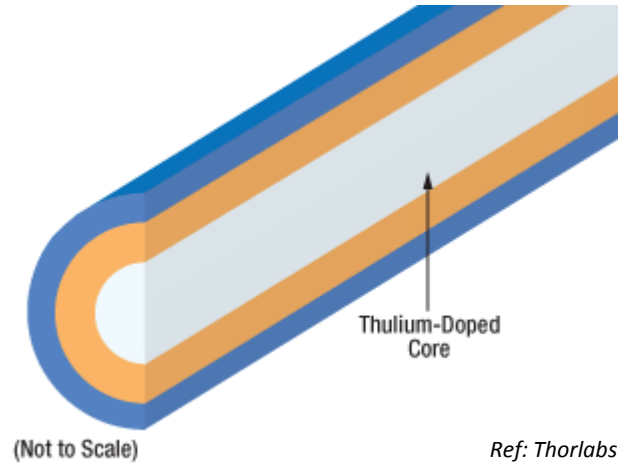
Material processing



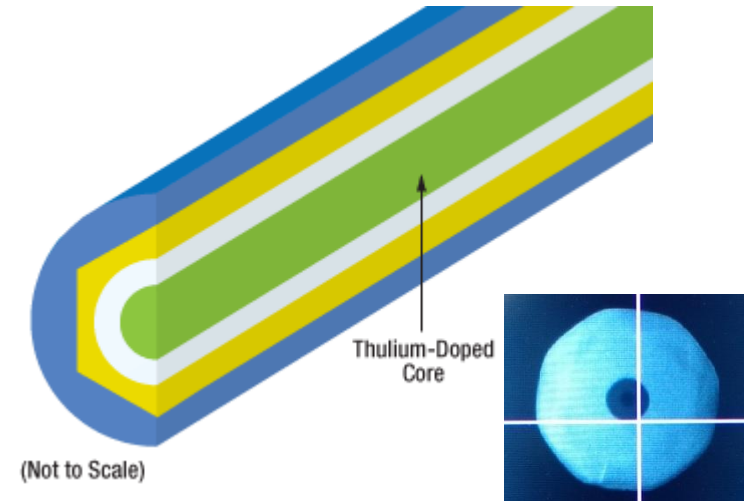
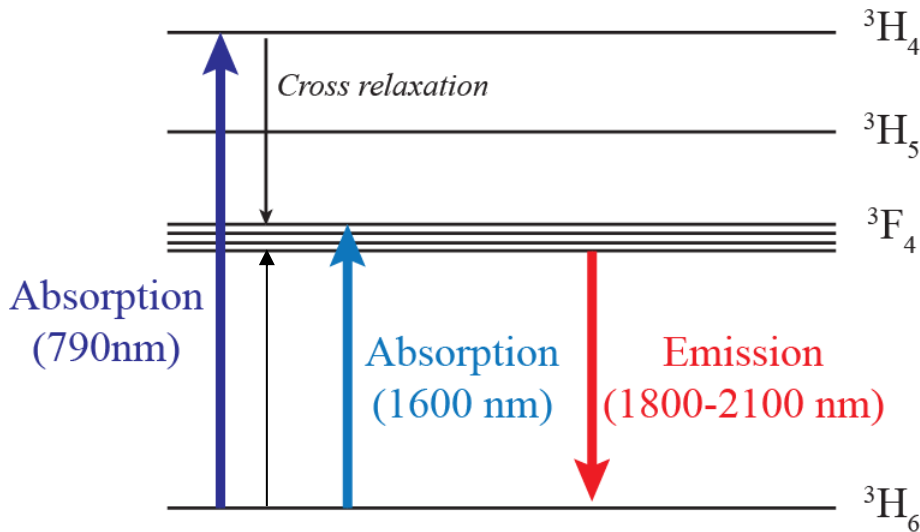
Thulium doped fibers



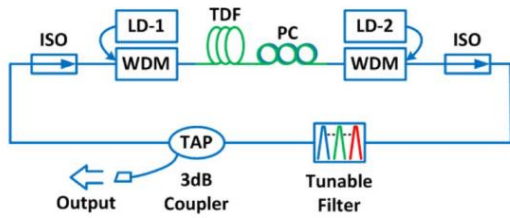
Ref: Daniel Creeden, et al. *Opt. Express* **22**, 29067-29080 (2014)



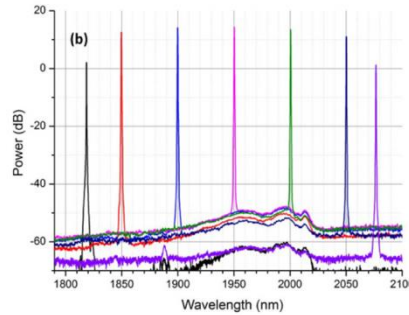
Ref: Thorlabs



2 micron fiber lasers



Ref: Z. Li, et al., *Opt. Lett.* 2013



Ref: Z. Li, et al., *Opt. Exp.* 2013

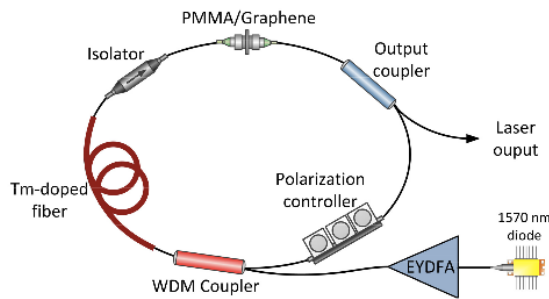
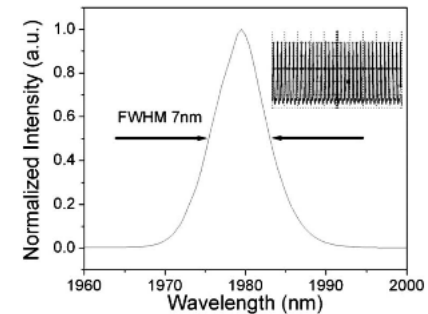
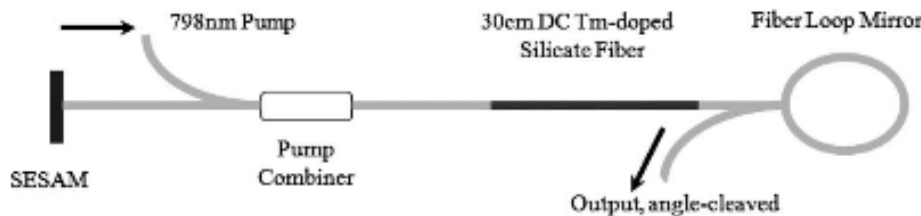
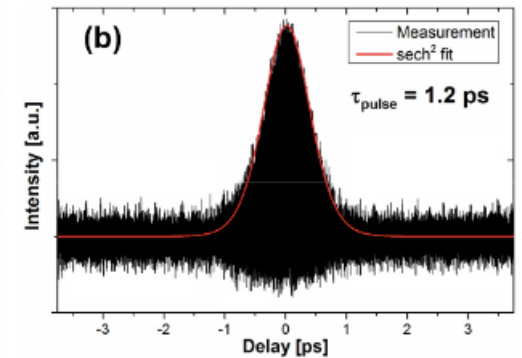
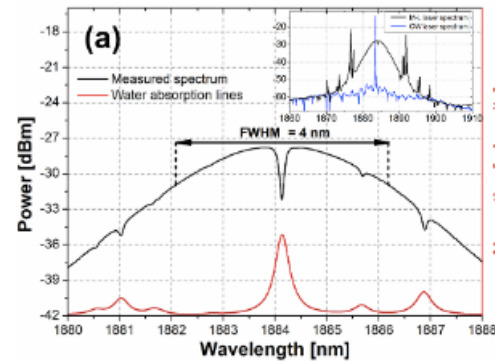


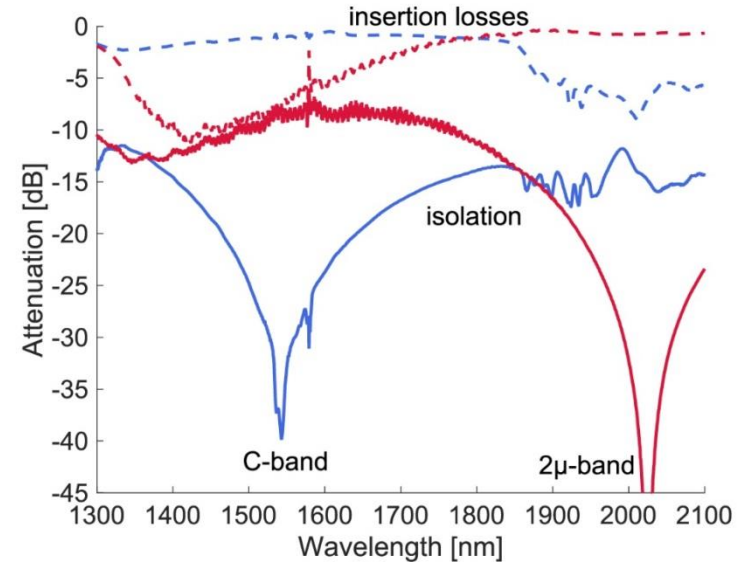
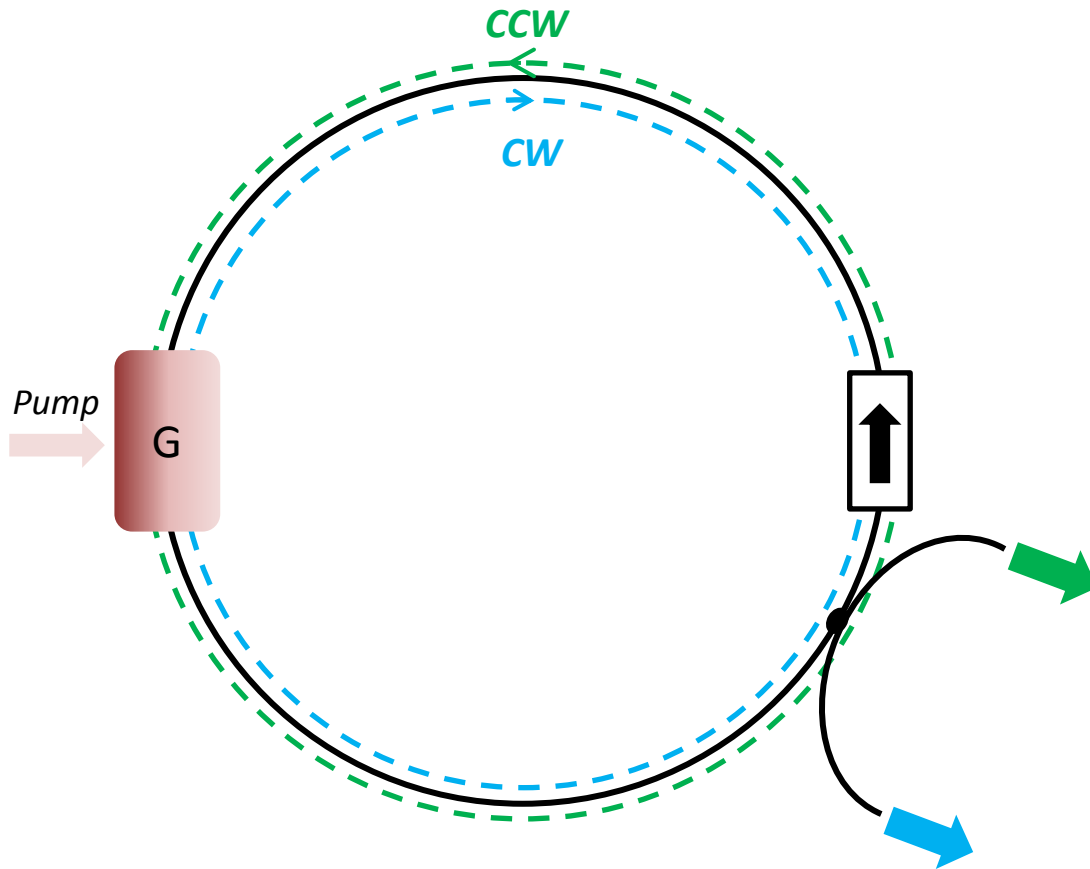
Fig. 2. Experimental setup of the Tm-doped fiber laser.

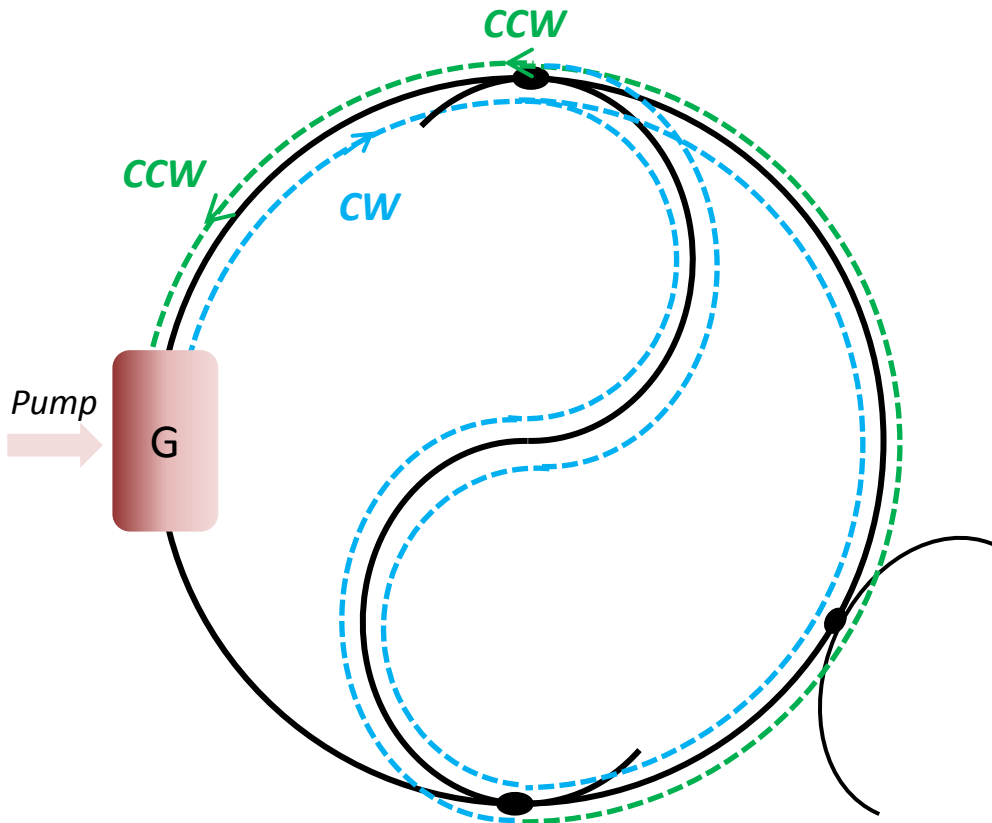
Ref: Grzegorz Sobon, et al." *Opt. Express* 21, 12797-12802 (2013)



Ref: Q. Wang, et al. *Opt. Letters* 34 (23), 2009

UBidirectional ring cavity





Unidirectional theta cavity

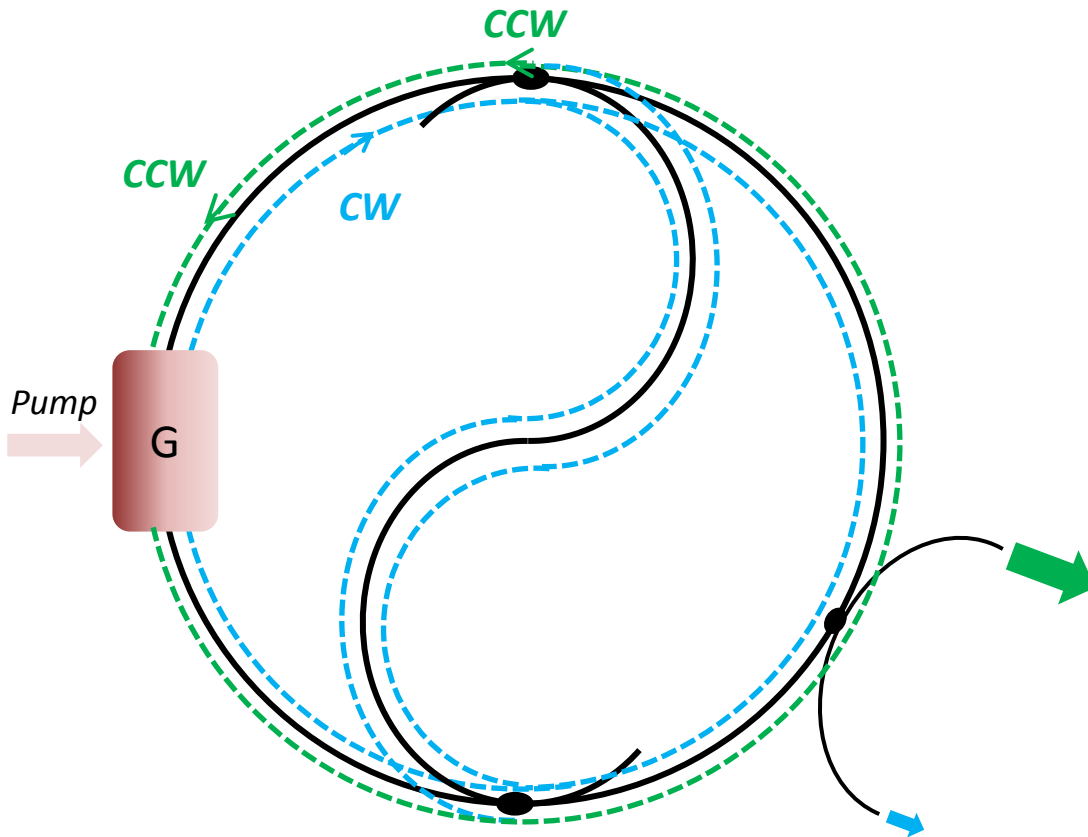
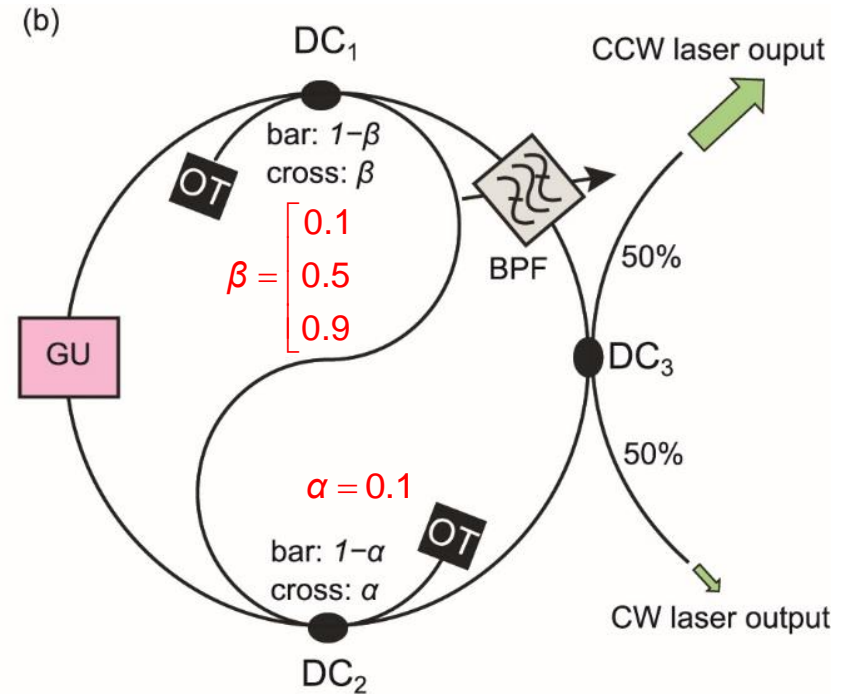
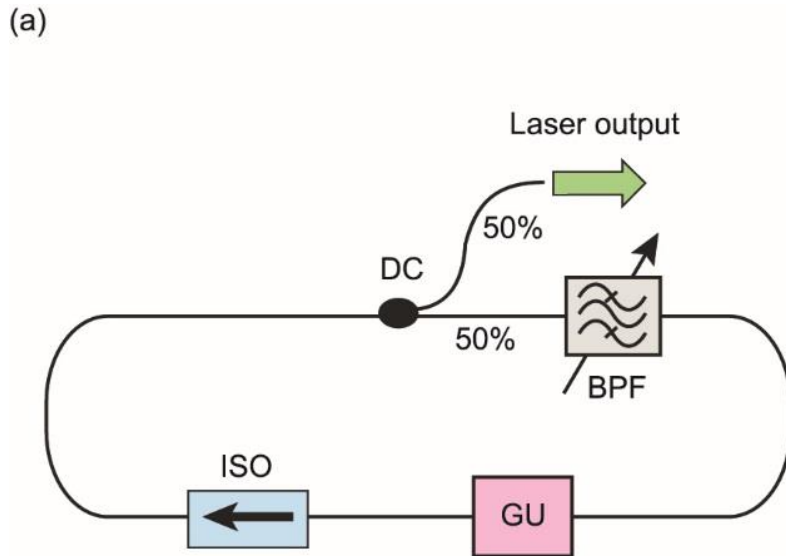


Figure of merit: extinction ratio

$$ER = \frac{P_{CCW}}{P_{CW}}$$

- Erbium-doped fiber laser (20 dB)
Shi, Y. et al. IEEE Phot. Tech. Lett. 7, 290–292 (1995)
- Semiconductor laser (20 dB)
Hohimer, J. P. et al. Appl. Phys. Lett. 63, 2457 (1993)
- Quantum-dot-in-a-well laser (30 dB)
Cao, H. et al. Appl. Phys. Lett. 86, (2005)
- Quantum cascade laser (10 dB)
Nshii, C. C. et al. Appl. Phys. Lett. 97, 231107 (2010)

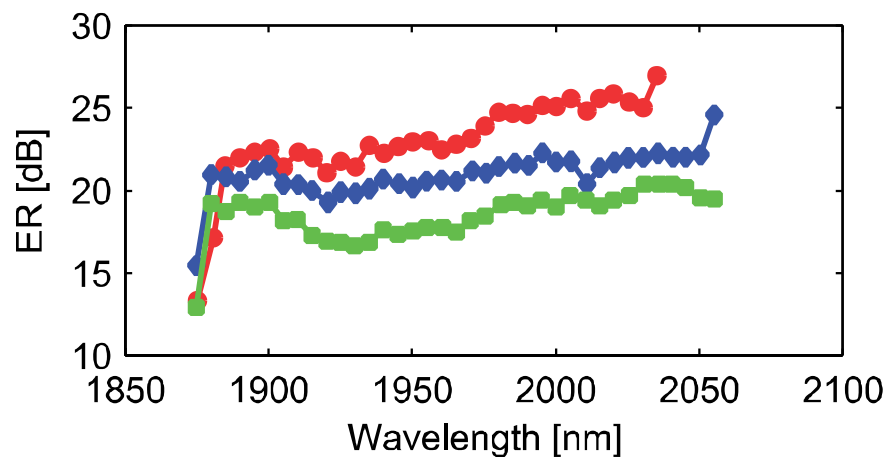
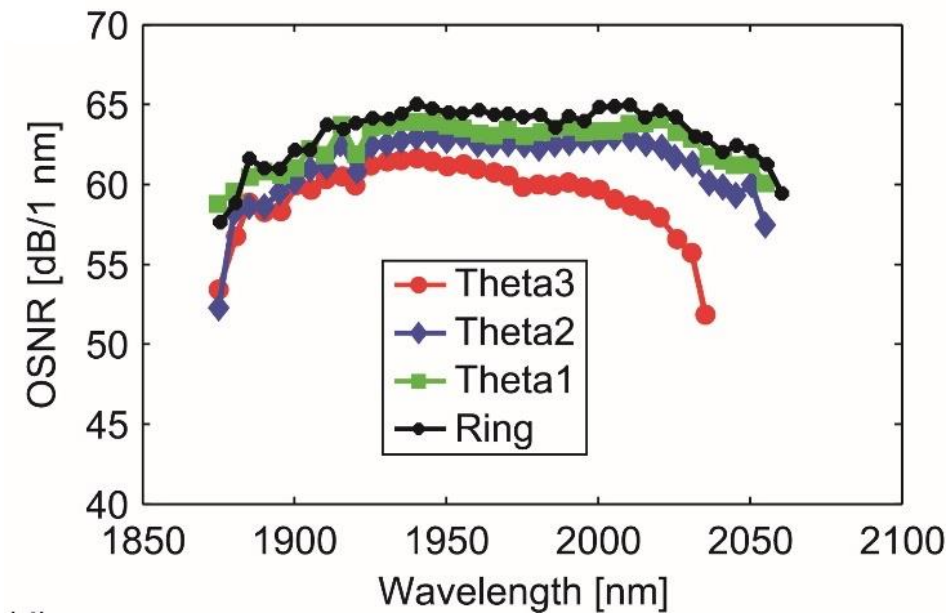
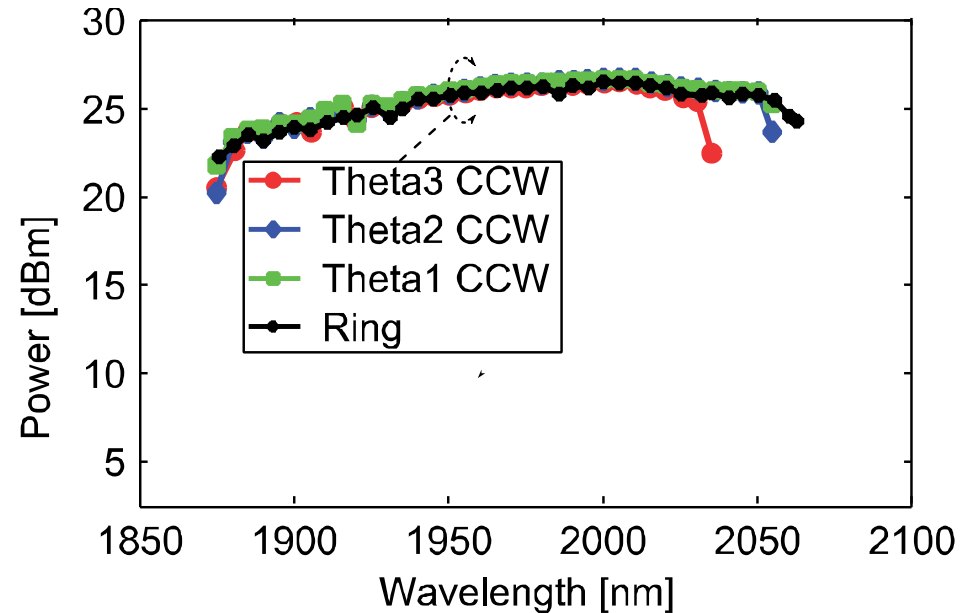
Comparison between ring and theta cavities



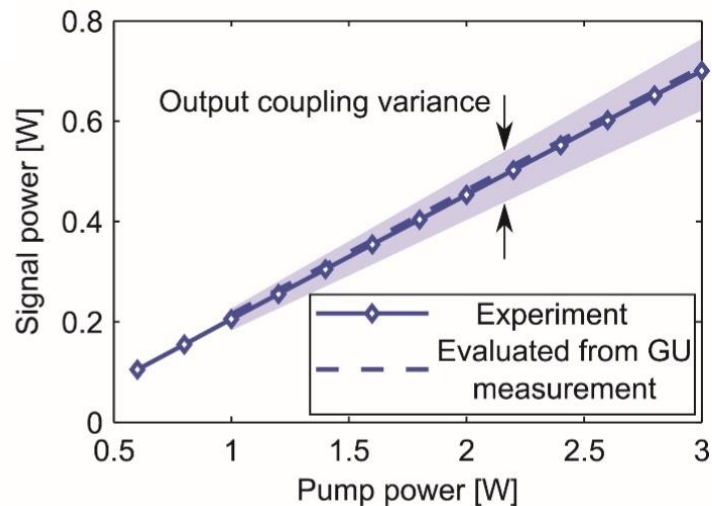
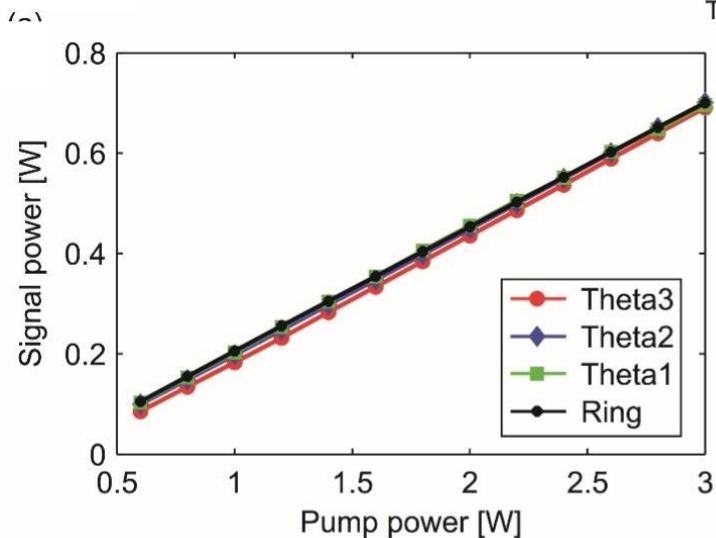
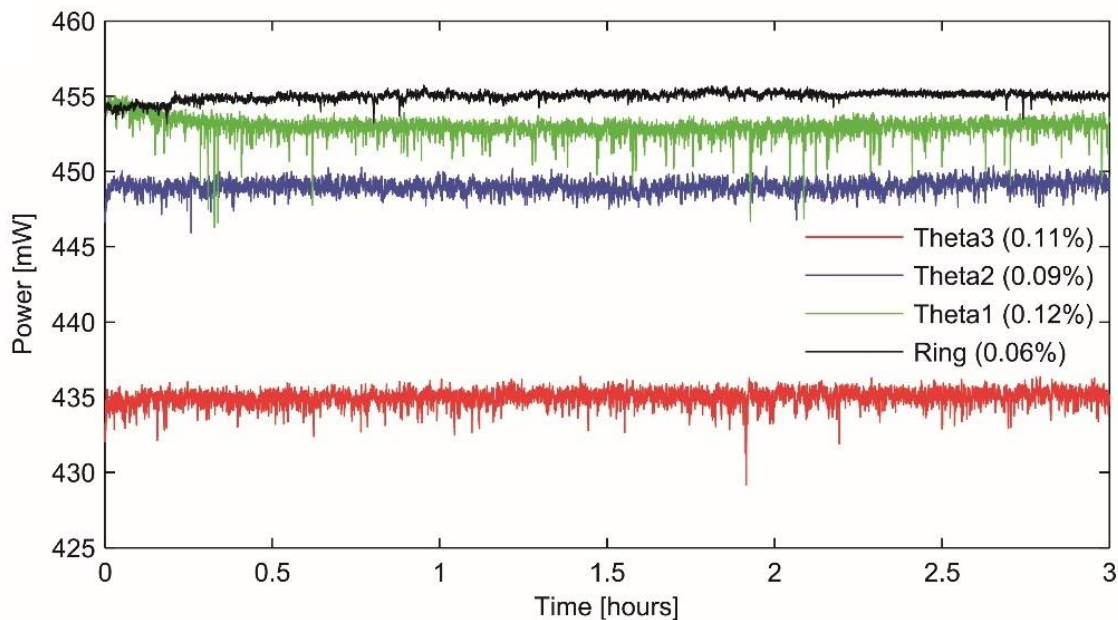
Similar to: Li, Z. et al. All-fiber, ultra-wideband tunable laser at 2 μm . *Opt. Lett.* 38, 4739–42 (2013)

GU: gain unit; BPF: band pass filter; ISO: optical isolator; DC: directional coupler; OT: optical terminator.

Experimental results

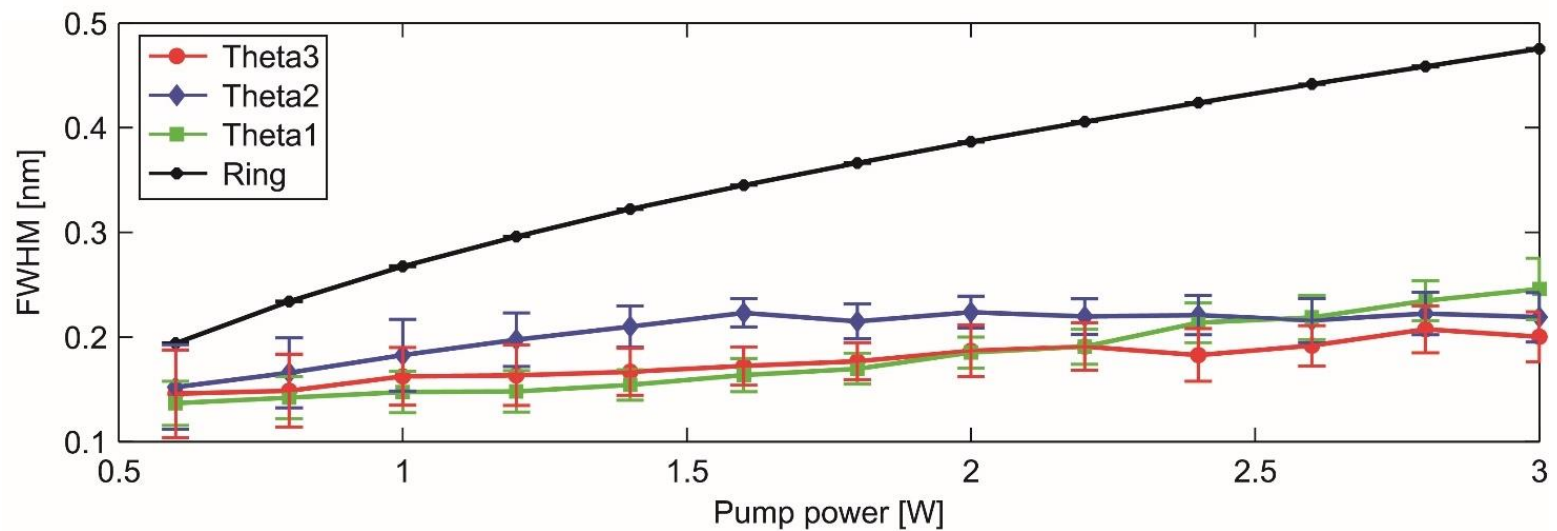
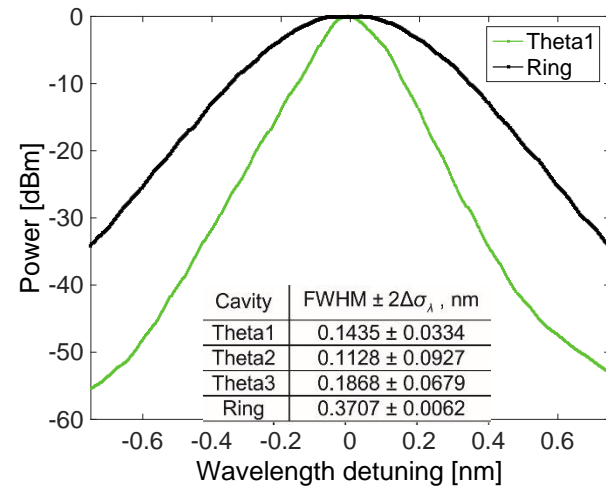
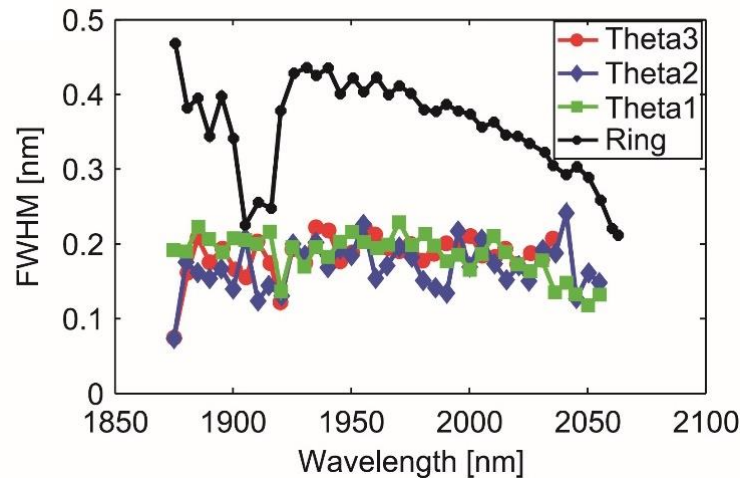


Ref: S. Kharitonov, C.-S. Brès, *Light: Science & Applications* (2015) **4**, e340;



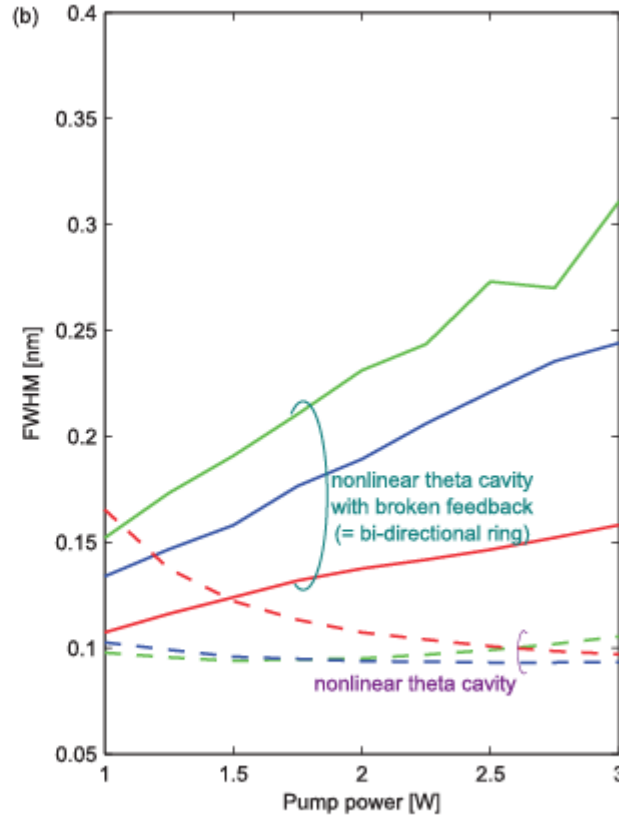
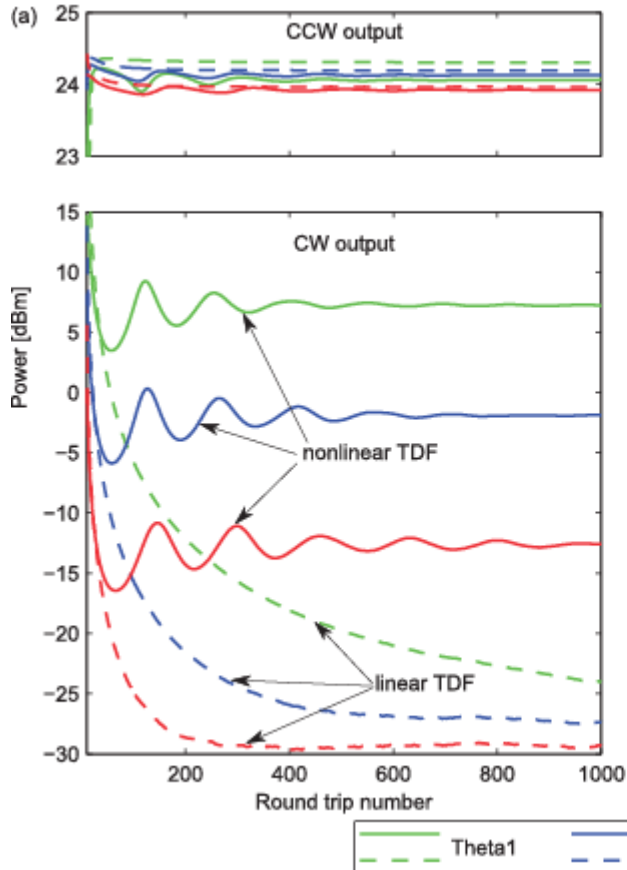
Ref: S. Kharitonov, C.-S. Brès, *Light: Science & Applications* (2015) **4**, e340;

Experimental results - linewidth



Ref: S. Kharitonov, C.-S. Brès, *Light: Science & Applications* (2015) **4**, e340;

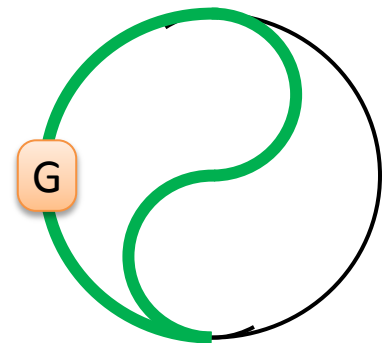
Simulation – nonlinearities ?



The TDF nonlinear coefficient γ is 5 times higher than that of SMF-28

Ref: Kharitonov, S. et al. CLEO, 2015, JTU5A.31.

Nonlinear-amplifying loop mirror (NALM) in the cavity?



Ref: Fermann, M. E. et al. Opt. Lett. **15**, 752 (1990).

- ❑ Increasing output power
 - Core pumped with single mode 793 nm diodes
 - Double clad pump with multimode 793 nm diodes

- ❑ Pulsed operation
 - Modelocking – SESAM, NOLM, NPR

- ❑ Multiwavelength operation
 - Cascaded Brillouin

- ❑ Operating Bandwidth extension
 - Thulium doped ZBLAN

