# Stabilization of the unidirectionality phenomenon observed in a fully reciprocal fiber ring laser by retarding the seeding of Raman stokes

**Muhammad Assad Arshad**[1,2], **Dr. Alexander Hartung**[1], **Dr. Matthias Jäger**[1]

*1. Leibniz-Institute for Photonic Technology, Albert Einstein Str. 9, 07745 Jena, Germany*

*2. Friedrich Schiller University, Faculty of Physics and Astronomy, Max-Wien-Platz 1, 07743 Jena, Germany*

Recently a new form of unidirectionality was observed in a fully reciprocal fiber ring laser [1]. In contrast to the established forms of directionality induction e.g. by using components like circulators and isolators [2] or special cavity arrangements [3], this new form of unidirectionality requires no additional directional components. Moreover, unlike [4] the unidirectionality is observed at full laser operation far above the laser threshold. As no additional components are required, the new approach has the potential to circumvent any power and spectral constraints traditionally associated with directional devices, therefore making the approach suitable for high power and broad wavelength applications. Moreover, as it a previously unobserved phenomenon, there is potential for better understanding regarding the possible combination of known physical effects at play.

The setup in use is shown in Fig. 1a. It is a simple ring cavity including a pump diode, a power signal combiner (PSC), a Yb doped active fiber section, an output coupler (OC) or a WDM to couple some part of the light out and finally a km long section of passive Corning's HI-1060 fiber. As no directional components are involved the cavity initially starts its operations in the bidirectional regime where almost equal amount of power is emitted from the two counterpropagating directions. The situation changes as soon as pump power is increased, where above a certain threshold (named as switching power $P_S$) the output power from one (preferred) direction experiences a sudden increase while the opposite direction effective switches off and the cavity enters the unidirectional regime. In terms of the output spectrum (Fig. 1b), due to km long lengths of fiber involved the emitted spectrum is broadened due to stimulated Raman scattering (SRS), which further smoothens in the unidirectional regime. We have observed that the preferred direction in the unidirectional regime can be predefined with up to 100% certainty by managing the roundtrip losses and the $P_S$ follows a power times length scaling [1], which is typical for thresholds associated with nonlinear phenomena like SRS. We therefore think that the underlying causes are nonlinear in nature.

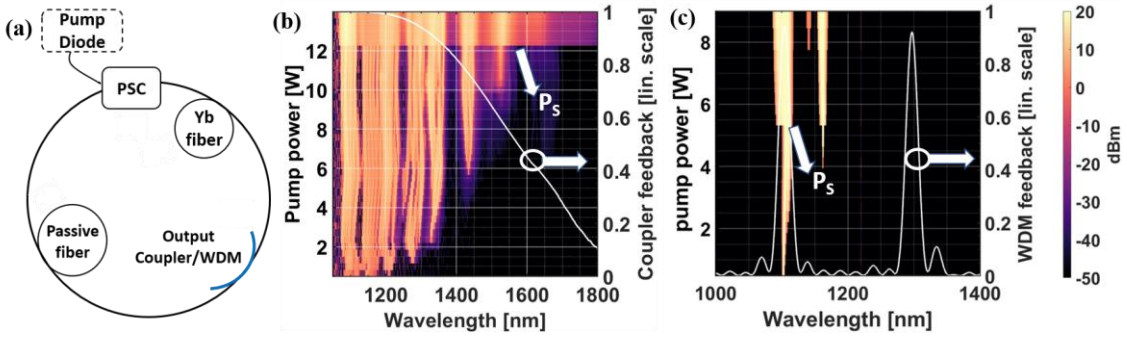


**Fig. 1** a) Experimental setup. Excited spectrum of the preferred direction and feedback profile b) with a 0.01% output coupler (OC) and c) a WDM series suppressing SRS. $P_s$ stands for the switching power at which cavity enters the unidirectional regime.

To investigate this further, we decided to inhibit the spectral broadening due to SRS by coupling the excited Stokes out of the cavity by using a series of WDMs in place of the OC. WDM series effectively act as the filter stage that hinders the seeding of Stokes by coupling them out of the ring. The results are shown in Fig. 1c), here we observe that the inhibition of spectral broadening results in more than 50% decrease in the $P_s$. Furthermore, limiting spectral broadening results in a consistent directional preference (counter clockwise) in the unidirectional regime. Moreover, the cavity also stabilizes in terms of $P_s$ and output powers i.e. for multiple runs the $P_s$ and output powers were highly reproducible. This is beneficial as this enables us to reduce cavity lengths considerably but still inducing unidirectionality at manageable pump powers, an essential step towards commercial realization of this phenomenon.

## References

1. M. A. Arshad, A. Hartung, A. C. Pratiwi, and M. Jäger, "Observation of direction instability in a fiber ring laser," Sci. Rep. **11**(1), 4436 (2021).
2. D. Jalas, A. Petrov, M. Eich, W. Freude, S. Fan, Z. Yu, R. Baets, M. Popović, A. Melloni, J. D. Joannopoulos, M. Vanwolleghem, C. R. Doerr, and H. Renner, "What is — and what is not — an optical isolator," Nat. Photonics **7**(8), 579–582 (2013).
3. S. Kharitonov and C.-S. Brès, "Unidirectional all-fiber thulium-doped laser based on theta cavity and fiber Bragg grating as filtering element," in *Lasers Congress 2016 (ASSL, LSC, LAC)* (OSA, 2016), p. AM5A.5.
4. W. J. Lai, P. Shum, and L. Binh, "Bidirectional optical bistability in a dual-pumped erbium doped fiber ring laser.," Opt. Express **12**(23), 5640–5 (2004).