All-fiber ring interferometer with an optical control of the resonance

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We report on the experimental study of Rayleigh scattering in all-fiber ring interferometer with an optical control of the resonance. This control is achieved through the refractive index change (RIC) effect in single mode ytterbium-doped optical fiber. The index changes are induced by an optical pumping at the resonant wavelength within the active fiber absorption line. During the experiment the ring interferometer is excited by a narrow-line laser at 1550 nm, while the control optical signal at 980 nm is used to adjust the cavity resonance to the laser excitation wavelength leading to enhanced generation of the Rayleigh backscattering.

Introduction

The phenomenon of light interference is underline for number of high-precision systems and motion sensors. Using the optical fibers, we can make such devices extremely compact and cost-saving.

In recent years, due to the intensive development of the fiber lasers, it is observed a growing interest in the fiber ring applications, for example as optical sensors or optical data buffering [1]. This paper includes the experiment study of the all-fiber ring interferometer with an optical control of the resonance and, in particular, the effect of Rayleigh backscattering in this interferometer. Rayleigh scattering is a fundamental threshold-free loss mechanism in optical fiber arising from density fluctuation frozen into the fused silica fiber during its manufacture [2]. It demonstrates unique spectral, temporal-spatial properties that could be exploited for lasing control in fiber lasers. The mechanisms of the light scattering could be naturally implanted to the fiber laser by means of a passive all-fiber configuration that operates as a dynamical mirror [3]. In the current work, we extend the functionality of such mirror providing it with the control of the resonance frequency by an external optical signal. The control of the resonance is achieved through the refractive index change (RIC) effect [4 - 10] induced in a single mode ytterbium-doped optical fiber by an optical pumping at the wavelength within the ytterbium absorption line. The most common application for the reported interferometer is to operate as Rayleigh mirror employed with passively Q-switched fiber lasers [11, 12]. We suppose that it would allow to overcome the main disadvantages of the traditional Rayleigh mirrors, such as their high sensitivity to the external environment perturbations (acoustic, mechanical, thermal noises) that cause stochastic drift of the interferometer resonant frequency from the resonance operation position.

Experimental setup

The experimental configuration of fiber ring interferometer is illustrated in Figure 1. The interferometer is entirely made up of about 8 m of conventional silica optical fiber laid in a ring configuration. The ring includes a single mode fiber coupler (90/10), a wavelength-division–multiplexing coupler (WDM) 980 nm/1550 nm, a 1.5 meter length section of ytterbium-doped optical fiber, and a passive fiber stop-band filter which prevents lasing within the emission spectrum of the ytterbium fiber. The narrow-line CW-radiation of the laser diode "Tunics" at the wavelength $\lambda_T = 1550\, nm$ and with a coherence length of ~ 10 m is used as an optical signal exciting the Rayleigh mirror. A laser diode operating at the wavelength $\lambda_P = 980\, nm$ is used for pumping the ytterbium fiber inside the ring cavity through the WDM coupler. One of the fiber coupler output (Output 1) is used for monitoring of the radiation at 1550 nm passed through the interferometer. The circulator (Output 2) and is used to control the optical signal backscattered by the interferometer (i.e. the signal reflected by the Rayleigh mirror).

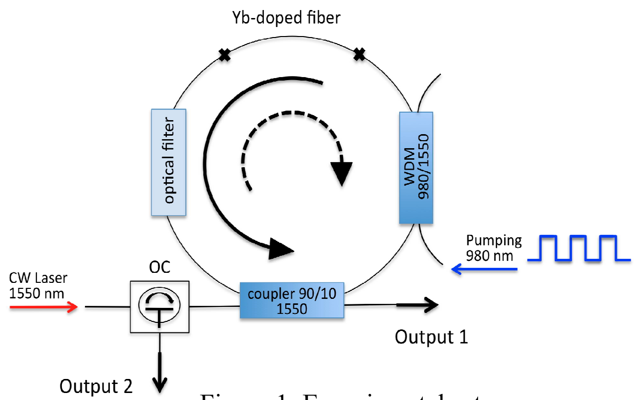

Figure 1. Experimental setup

Experimental results

For optical tuning of the interferometer resonance, the Yb-doped fiber inside of the cavity is pumped by the laser diode at $\lambda_P = 980\, nm$. The pump power is square modulated through the current driving circuit. The pump pulse applied to the fiber is $\tau_P = 4\, ms$ duration. An increase of the pump power up to ~80 mW leads to a phase shift up to 3π recorded at 1550 nm for the ring cavity length (Figure 2).

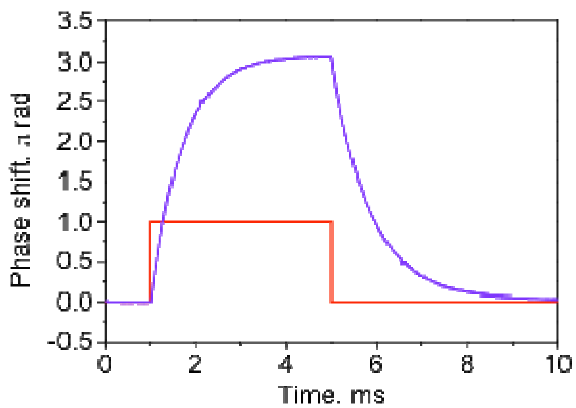

Figure 2. Recorded phase trace (blue) and laser diode power profile (red)

The achieved phase shift is a direct result of the electronic refractive index change effect in the Yb-doped fiber described by the equations:

$$\delta\varphi(t) = K\tau_{sp}\left[1-\exp\left(-\frac{t}{\tau_{sp}}\right)\right]P_0 \,,\, 0<t<\tau_P$$

$$\delta\varphi(t) = K\tau_{sp}\left[\exp\left(\frac{\tau_P}{\tau_{sp}}\right)-1\right]\exp\left(-\frac{t}{\tau_{sp}}\right)P_0 \,,\, t>\tau_P$$

where P_0 is the pump pulse amplitude, τ_{sp} is the Yb-ions exited state life-time, and K is a coefficient given in [6 - 9]. Dynamical tuning of the phase shift is followed by the tuning of the ring optical length and hence tuning of the interferometer resonance frequencies with the spacing

$$\Delta\nu = \frac{c}{nL},$$

where c is the speed of light, n is the fiber refractive index, L is the resonator optical length. When one of the resonance frequencies of the interferometer passes through the frequency of the exciting laser, the interferometer starts to accumulate the laser radiation inside the cavity leading to the characteristic peak observed in passed radiation (Figure 3).

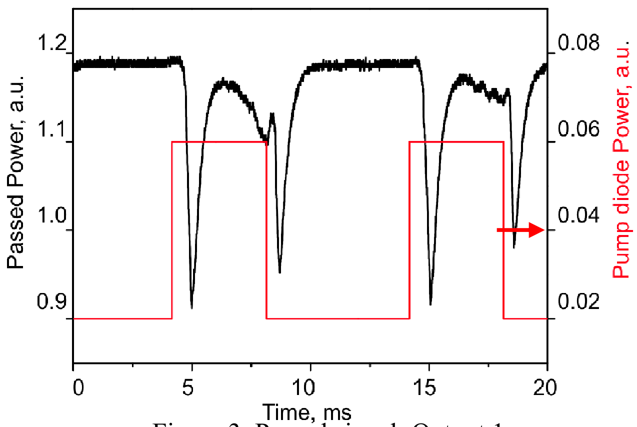

Figure 3. Passed signal: Output 1

Simultaneously, the efficiency of the Rayleigh scattering is drastically enhanced causing the Rayleigh mirror effect shown in Figure 4.

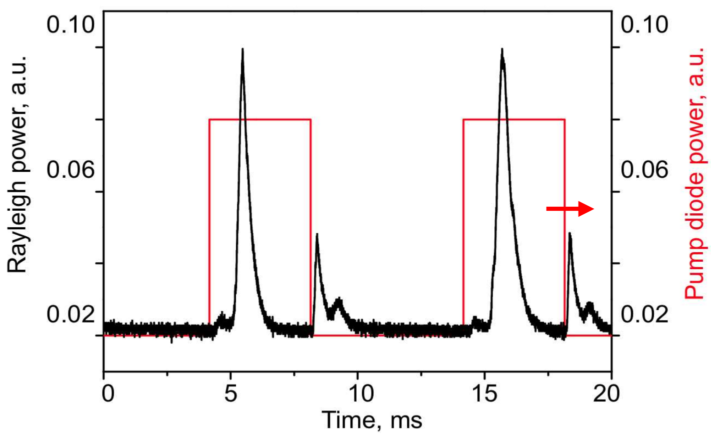

Figure 4. Reflected signal: Output 2

Conclusion

We have reported the method of optical control and tuning of the ring interferometer within one intermode frequency space. The method is demonstrated to be efficient with Rayleigh mirrors used for all fiber laser applications.

The proposed controllable all-fiber ring interferometer can be used for an active compensation of the undesirable noise perturbations in optical sensors, for example in optical gyro. Reasonable use of the studied processes in optical fibers, drawing the undesirable losses in fiber (such as Rayleigh backscattering) into the useful effects, is an important trend of the modern fiber optics [13].

Acknowledgements

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