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Reflectivity measurement of fiber Bragg grating by cavity ring-down spectroscopy technique

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ABSTRACT

A novel method to measure the reflectivity of fiber Bragg grating (FBG) is proposed and demonstrated experimentally. A kind of fiber Bragg grating FP(FBG-FP) cavity is constructed, which includes a couple of identical uniform FBG as the cavity mirrors linked by a piece of Er-doped fiber. The response of FBG-FP cavity to pulsed laser injection is demonstrated theoretically and experimentally, and the effect of the reflectivity of FBG to the output of FBG-FP cavity is discussed. The reflectivity of FBG is achieved by measuring the transmission loss of FBG-FP cavity with cavity ring-down spectroscopy technique. A general relationship between the reflectivity of FBG and ring-down time of FBG-FP cavity is derived. It's demonstrated that the output loss of FBG-FP cavity increases as the reflectivity of FBG decreases, the stable light intensity in the cavity decreases fastly, and the ring-down time of the FBG-FP cavity decreases, the operating wavelength of FBG is a function of its temperature. The results demonstrate a new concept of the measurement of reflectivity of FBG and the technical feasibility.

1. Introduction

Fiber Bragg grating (FBG) has attracted much attention for its wide applications in fiber optic sensing, microwave photonics, optical communication systems, laser technology, optical information processing and other fields [1–8]. The related parameters describing FBG are Bragg wavelength and bandwidth, grating period, grating length and reflectivity. The grating length and period can be accurately controlled in fabrication, and the Bragg wavelength and bandwidth can be obtained by experiment. However, the reflectivity of FBG is only obtained by theoretical calculation methods such as coupled mode theory, and the real experimental measurement of FBG reflectivity is rarely reported till now.

Cavity ring down (CRD) spectroscopy is a technique for measuring laser resonator loss. It was widely used in atomic and molecular physics, sensors, microwave / millimeter wave photonics and other fields [9–13].

A laser resonator with optical positive feedback has various losses. The laser cavity loss refers to the intensity attenuation of light caused by various physical reasons when it propagates in the cavity. The laser resonator losses include geometric diffraction loss, transmission loss, output mirror loss (i.e. transmission loss), non-active absorption loss, and scattering loss etc. The transmission loss is related to the reflectivity of cavity mirrors, which can be obtained with cavity ring-down spectroscopy technique by using the relationship between the reflectivity of cavity mirrors and the transmission loss of cavity. Recently, Gong Yuan et al. applied the CRD technique into the measurement of high reflectivity mirrors, the reflectivity up to 99.925% was obtained [14]. However, for the resonator composed of two independent cavity mirrors, it is the key that the two cavity mirrors are placed coaxially, Qu Zhechao

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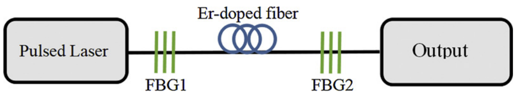

Fig. 1. Schematic diagram of output ring-down spectroscopy test for FBG- FP cavity.

et al. studied the effect of optical element misalignment in the cavity to high reflectivity measurement, the conclusion obtained provides a theoretical basis for high reflectivity measurement of non-coaxial resonator systems [15]. Now, the fiber Bragg grating FP (FBG-FP) cavity, composed of a couple of identical uniform FBGs used as the cavity mirrors connected by a piece of fiber, is a kind of all-fiber resonator, in which the coaxial mirror problem does not exist, and is widely used in laser and optical fiber sensing systems due to its simple structure.

In this paper, the reflectivity of FBG is measured by using FBG-FP cavity ring-down spectroscopy technique, and the feasibility of this method is demonstrated.

2. Theoretical analysis

The schematic diagram of the FBG cavity ring-down spectroscopy test system is shown in Fig. 1. The proof of concept device consists of a FBG-FP cavity with a couple of identical uniform fiber Bragg gratings (FBG1 and FBG2) connected by a piece of Er-doped fiber, and a pulsed laser source.

The pulsed laser with the amplitude of E_0 and intensity of I_0 ($I_0 \propto E_0^2$) is injected into the FBG-FP cavity and the single phase shift of light propagating in the cavity is as follows:

$$\varphi = \frac{4n\pi L}{\lambda} \tag{1}$$

Where, the n is the effective refractive index of the Er-doped fiber, L is the length of FBG-FP cavity, and λ is the incident light wavelength.

Ignoring the fiber absorption loss, without considering the nonlinear effect, the complex cavity field amplitude after p accumulated roundtrip will be [16]

$$E_1 = \frac{1 - r^{p+1}\exp[-i\varphi(p+1)]}{1 - r\exp(-i\varphi)}E_0 \tag{2}$$

Where, $i = \sqrt{-1}$, r is the attenuation factor of FBG FP cavity.

When the injecting phase of light is stopped, the remaining light in the cavity is still to circulate within the resonator for q additional roundtrips, the total electric field after the FBG-FP cavity can be written as:

$$E_2 = r^q\exp(-iq\varphi)E_1 \tag{3}$$

Substituting (2) into (3), we have

$$E_2 = r^q\frac{1 - r^{p+1}\exp[-i\varphi(p+1)]}{1 - r\exp(-i\varphi)}\exp(-iq\varphi)E_0 \tag{4}$$

The intensity of the output light field is:

$$I = E_2E_2^* \tag{5}$$

Where E^* is the conjugate of E. The ratio of output intensity to input intensity, R, is:

$$R = \frac{I}{I_0} \tag{6}$$

The parameters used in the simulation are as follows: the cavity length is 0.2 m, the incident wave length is 1550 nm, p = 0…

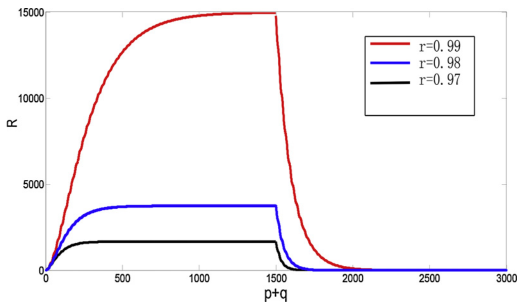

Fig. 2. Response of FBG-FP cavity to pulsed laser injection.