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Comparison of three technique of Brillouin lidar for remote sensing of the ocean

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ABSTRACT

Three methods used to achieve Brillouin lidar in actual application are discussed. The scanning F–P interferometer technique cannot make real time measurement although it is high accurate. The edge technique has high sensitivity, but it requires extreme strict stable condition on environment. The technique combining F–P etalon and intensified CCD (ICCD) can stably work with few requirements on environment, and can make real time measurement. Therefore, the technique combining F–P etalon and ICCD will be the good choice for achieving Brillouin lidar practically.

1. Introduction

Brillouin lidar [1–3] is a new and developing technique for the remote sensing of the ocean. It can be used for the real time measurements of sound speed in the water [4,9], temperature of the water [2,3,10,12], salinity of the sea water [3], and attenuation coefficient of the water [13]. Also, it can be used for detecting submerged object [6]. The present authors did a lot work [14–17] on the Brillouin lidar,and improved the systems by three techniques. Recently, professors Kun Liang and Yong Ma proposed a processing method of spectral measurement can improve greatly the performance of Brillouin lidar. About the principles and techniques for Brillouin lidar had been reported in details, it is not mentioned in this paper.

Up to now, there are three techniques for receiving Brillouin lidar echo signal practically: the scanning F–P interferometer (FPI) technique [4,9], the edge technique [7,18,19] and the technique combining F–P etalon and intensified CCD (ICCD) [14]. However, the advantages and disadvantages of every technique have not yet been analyzed, and which one is more suitable for actual application has not yet been discussed. In the present work, the suggestion for choosing a better technique is given and then improve the Brillouin lidar system based on the analysis of the characteristics of each technique.

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2. Three techniques for achieving Brillouin lidar

2.1. Scanning F–P interferometer technique

Scanning F–P interferometer technique is the basic method for measuring many kinds of spectroscopies. It was also used in Brillouin lidar [4,8,9,11]. Fig. 1(a) shows schematically the optical layout for a lidar using scanning F–P interferometer technique. While Fig. 1(b) gives a measured spectrum using the lidar system shown in Fig. 1(a). It can be seen that, the integrated spectrum including the whole spectral information is recorded. From the spectrum, the Brillouin shift and Brillouin line width can be determined by the free spectral range (FSR) of the FPI. Based on the relationship between the ocean parameters and the spectral characteristics the ocean parameters can be obtained, such as, sound speed in the water [4,5,9], temperature of the water [2,10,11], viscosity of the water [8], attenuation coefficient of light in the water [13], and the salinity of the sea water [3]. So, the Brillouin lidar using FPI technique can measure several ocean parameters. Very high measuring accuracy can be obtained as long as the FPI is fabricated in high precision. For a FPI with the FSR of 20 GHz, the accuracy of 1 MHz could be reached at. the Another advantage of FPI technique is that, a photomultiplier tube can be used as the detector, it makes the lidar system has high sensitivity.

The relationship between sound speed V_S [4,9] in the water and Brillouin shift ν_B is defined as [2]

$$\nu_B(S,T)=\frac{2n(S,T)}{\lambda}V_S(S,T)\sin\left(\frac{\theta}{2}\right) \tag{1}$$

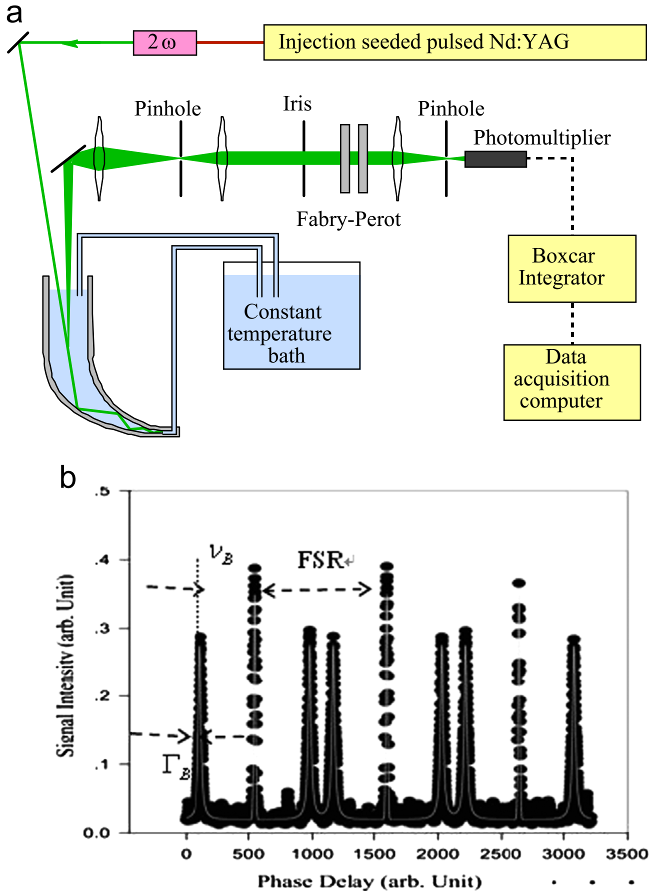

Fig. 1. (a) Optical layout for scanning F–P interferometer method used in Brillouin lidar. (b) Spectrum of Brillouin scattering measured using optical layout in (a). FSR is the free spectral range of the etalon, ν_B and Γ_B are the Brillouin shift and Brillouin line width respectively.

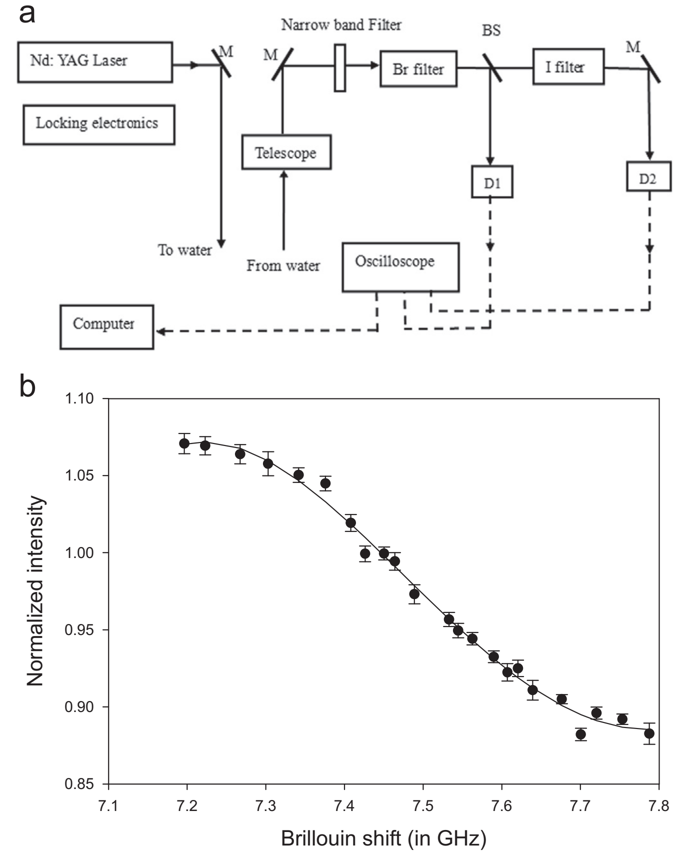

Fig. 2. (a) Set-up geometry of experimental measurements. M is mirror, BS is beam splitter. The narrow band filter is A multiplayer interference filter with a bandwidth of 3 nm and a transmission of 62%. D1 and D2 are detectors. Br filter is an absorption cell of Br^{79}. I filter is an absorption cell of I^{127}. (b) Measured results of Brillouin shift using edge technique.

Generally, more accurate result could be obtained using an empirical relation for the dependence of V_S on salinity S and temperature T [4,9]

$$V_S(S,T) = C_0 + C_1T + C_2T^2 + C_3T^3 + C_4S + C_5S^2 + C_6TS + C_7T^2S \quad (2)$$

here C_i are the known value [9]. From Eqs. (1) or (2) the sound speed in the water can be obtained.

The measuring uncertainty of sound speed is expressed as [14]

$$\delta V_s = \sqrt{\left(\frac{\partial V_s}{\partial s}\right)^2 (\delta s)^2 + \left(\frac{\partial V_s}{\partial \nu_V}\right)^2 (\delta \nu_B)^2} \quad (3)$$

When the salinity of water is fixed at 35‰ and the accuracy of salinity is 0.1‰ by retrieving the data base, the uncertainty is related directly to the accuracy of the measurement of Brillouin shift.

It can be calculated that $\delta V_s \le 0.22$ m/s, when $\delta\nu_B = 1$ MHZ. The accuracy of 1 MHz could be easily reached used this technique as it was mentioned.

We measured the sound speeds at different temperatures with salinity at 35‰ and are given in Table 1.

Also, the bulk viscosity η_b of water can be determined by [8]

$$\eta_b = \frac{\rho V_s^2 \Gamma_B}{4\pi^2 \nu_B^2} - \frac{4}{3}\eta_s \quad (4)$$

here Γ_B is the Brillouin line width, ρ is the density of the water, and η_s is the shear viscosity of the water.

The measuring uncertainty of bulk viscosity is expressed as

$$\delta_{\eta_\nu} = \sqrt{\left(\frac{\rho V^2}{4\pi^2 \nu_B^2}\right)^2 (\Delta\delta\omega_B)^2 + \left(\frac{\rho V^2 \delta\omega_B}{2\pi^2 \nu_B^3}\right)^2 (\Delta\nu_B)^2} \quad (5)$$

It can be calculated $\delta_{\eta_\nu} = 1.022 \times 10^{-7}$ with these parameters:

$\nu_B = 7.5$ GHZ, $\delta\omega_B = 500$ MHZ, $\rho = 1000$ kg/m^3, $V = 1500$ m/s, $\Delta\nu_B = \Delta\delta\omega_B = 1$ MHZ.

The order of magnitude δ_{η_ν} is lower much than the measurement value of η_ν with order of magnitude of $\times 10^{-3}$, this mean the relative error is less than 0.1%.

But, several disadvantages limit the performance of FPI technique used in lidar system. (1) To make accurate measurement, the incident beam hitting on the FPI must be a strict collimated beam. This requirement may be difficult for practical environment in applications. (2) High power pulsed Nd:YAG laser running at

Table 1
Sound speeds at different temperatures with salinity at 35‰.

Temperature (°C)	2	3	4	8	10	15	20	23	25	30
Sound speed (m/s)	1450.28	1455.75	1463.67	1478.53	1490.69	1507.48	1520.14	1531.37	1543.07	1558.62