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Propagating of partially coherent laser beam in the near-resonant atomic gas

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ABSTRACT

The characteristics of the light with various degrees of spatial coherence traveling in near-resonant atomic gas are investigated both experimentally and theoretically. The experimental results show that the coherence of partially coherent beams can get better after interaction with atoms under some certain conditions compared with that before interaction. The experimental results are explained theoretically by the method of spectroscopy absorption. Furthermore, partially coherent light has a better environmental adaptability than fully coherent light.

1. Introduction

With its appealing characteristics, laser beam is applied to a variety of fields, such as laser communication, quantum control and precision measurement. Under ideal conditions, the laser beam is considered as the fully coherent beams (CB). However, we usually get the partially coherent beams (PCB) to use in application. In the past decades, scientists has studied PCB extensively both in theory and experiment which making PCB applied to a lot of fields, such as atom cooling [1], optical imaging [2], particles capture [3], geometrical optics [4], and free-space optical communications [5]. Compared to CB, PCB has a better performance in some areas, for example， improving the quality of holographic image [6] *etc*.

In particular, when propagating through an inhomogeneous media, PCB and CB present different performance concern with their spatial coherence properties, such as the fluctuation of coherence length [7] or the degree of polarization [8,9].

Most researches are concerned with the optical properties in intensity distribution and coherence change in the random or inhomogeneous media [10]. Banakh et al. prefer the Huygens-Fresnel integral for studying the propagation in turbulence [11]. Theoretical physicist suggested that PCB is less likely to be affected by atmospheric turbulence than CB [12–15]. Correspondingly, the similar results are verified in the experiment [16]. However, the characteristics of the light propagating in the near-resonant media are rarely explored. The absorbing medium is ideal for modulating both the phase and intensity of light. So, we can control the transmission characteristics of light through different optical thickness of absorbing medium.

In this paper, the characteristics of the light with various degrees of coherence traveling in near-resonant atomic gas are investigated both experimentally and theoretically. We found that the PCB's degree of coherence gets better than in the free space after travelling in the absorbing medium at some temperatures. With the temperature of the medium getting much higher, the degree of coherence degrades gradually. What's more, the PCB gains a slighter change in coherence than CB when both experiencing the same temperature variation, which means that PCB has a better environmental adaptability.

2. Principle of measurement and experimental apparatus

In the classical Young's interference experiment, the expression for the degree of spatial coherence of the laser can be written as

$$\gamma(r_1, r_2, 0) = \frac{\langle E_1(r_1, t) E_2{}^*(r_2, t)\rangle_t}{\sqrt{I(r_1)}\sqrt{I(r_2)}} \tag{1}$$

where the angular bracket $<\ >_t$ denotes the time average. r_1 and r_2 are the distances of two pinholes to the observation screen, respectively, $E(r_{1,2},t)$ is the light fields, $I(r_{1,2})$ is the intensity. The visibility of interference fringe is equal to the degree of coherence when the amplitudes of $E(r_1,t)$ and $E(r_2,t)$ are equal.

The expression of light intensity at the intersection of two beams is:

$$I(\mathrm{r}') = I_1(\mathrm{r}') + I_2(\mathrm{r}') + 2\sqrt{I_1(\mathrm{r}')I_2(\mathrm{r}')}\,|\gamma| \times \cos(\frac{2\pi \mathrm{r}' \cdot d}{\lambda D} + C) \tag{2}$$

where $I_{1,2}(r')$ is the intensity of the light field in the observation plane, d is the separation of pinholes, D is the distance from the double

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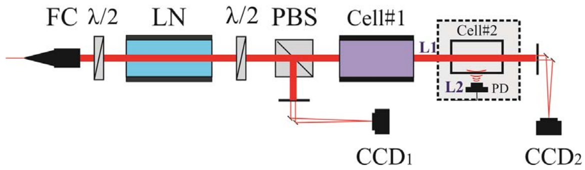

Fig. 1. Scheme of the experiment.

pinholes to the plane of observation.

In the experiment, we use the Lithium Niobate (LN) Crystal to produce the partially coherent light. If a modulation voltage is applied to the crystal in the direction perpendicular to the propagation direction of the light, a random phase is added to the light wave-front after passing through the crystal. The spatiotemporal distribution of the additional phase modulation depends on the frequency and amplitude of the modulation voltage, a detailed description of the experiment can be found in the previous work [1].

In our experiment, an external cavity semiconductor laser (ECDL) is applied to output a continuous laser with a wavelength locked to the resonant peak of ^{87}Rb $5^2S_{1/2}$, F=2→$5^2P_{3/2}$, F=3 [17], the central wavelength is 780.2nm with a bandwidth of 2MHz. Then the laser is coupled into a fiber as our light source. The experimental setup is shown in Fig. 1. We send the beam after LN crystal into the atom cell. Around the cell #1, there is the temperature controller, which is composed of the twisted-pair copper coils to avoid the disturbance of magnetic field. The temperature range can vary between 20 °C and 100 °C. We also have the flexibility to add a cell # 2 with constant temperature 20 °C after the cell #1 and place a photodiode (PD) to detect the spectral distribution, as shown in the dashed box of Fig. 1.

Firstly, we study the changes in light coherence after the LN. The LN crystal has one induced main axis after being added the voltage. The polarization of the outgoing light from crystal can be maintained for different modulated voltages, if the incident light keeps a specific direction of polarization. In our experiment, we use the typical Young's interference experiment to measure optical coherence of the output beam from the crystal. The lights coming from the two pinholes form the interference fringes, which detected by the CCD with pixel size of 4.5μm×4.5μm, as shown in Fig. 2. The spatial coherence of the laser can be deduced from the fringes to constitute the solid line in Fig. 3. From this curve, we can see that with the amplitude of crystal modulation voltage increasing, the coherence of light becomes smaller. This curve represents the coherence of light before it interacts with atoms.

From Fig. 3, we can see that when the PCB interacts with the atoms at the same temperature, the spatial coherence of the light becomes worse with the increasing of the amplitude of the modulation voltage.

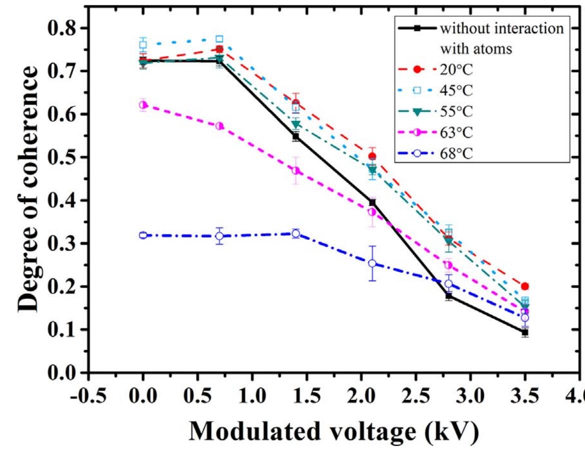

Fig. 3. The coherence of the beam as a function of the different modulation voltage. Solid line: without interacting with atoms. Other lines: after interacting with atoms at various temperatures.

In the temperature range of 20–55 °C, the degree of coherence is located above the solid line overall, indicating that at a certain temperature, the coherence of PCB turn to be better after interacting with atoms compared to the situation without atoms. The reason is that when the laser with a certain linewidth interacts with atoms, the spectra of outgoing light would change due to the absorbing, as shown in Fig. 4, 20 °C, 33 °C, 45 °C three fluorescence curves, which is detected by atom cell #2. This changing in the composition of spectra results in a better light coherence, which will be theoretically analyzed in detail in Section **3**.

Fig. 3 also shows that at small amplitude of modulation voltage with large degree of coherence, as the atomic temperature continues to rise, such as at 63 °C and 68 °C, PCB has obvious de-coherence. One reason is that when the atomic temperature is much higher, the refractive index of the medium fluctuates greatly, so that the phase disorder of the wave-front becomes intense and de-coherence gets more [18]. On the other hand, with the atomic temperature going higher, the interaction between light and the media become larger, and the intensity of the outgoing light attenuates heavily. At the same time, the line width of the outputting light also gets wider [19] as shown in Fig. 4, 63 °C, 68 °C, two fluoresce curves, which may lead to the worse of the coherence degree.

From Fig. 3, it also can be seen that the coherence fluctuation of the PCB is smaller than that of the CB by changing the temperature. It is believed that the randomness of the wave-front phase of the PCB counteracts the random phase induced by the heated gaseous medium

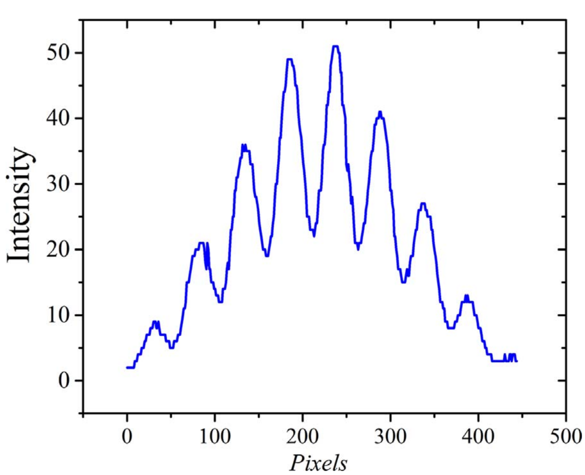

Fig. 2. The interference fringes recorded by CCD. The amplitude and frequency of modulation voltage on LN are 2.1 kV and 40 kHz, respectively.

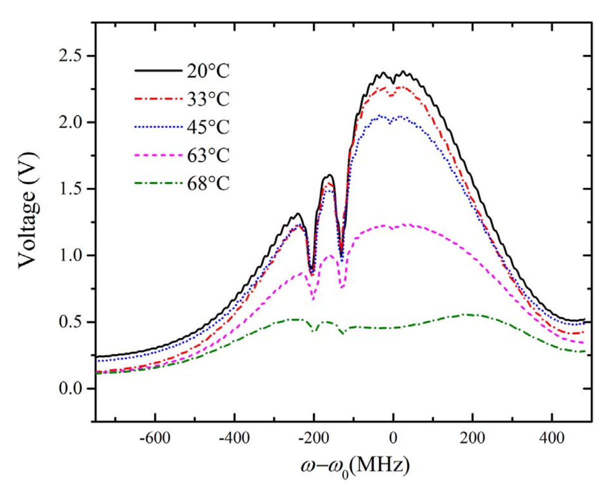

Fig. 4. The spectral distribution of outgoing light. The light interacts with atoms at different temperatures.