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Observation of the modulation instability and frequency-doubling in self-defocusing crystal

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ABSTRACT

We report on the experimental observation of the modulation instability of uniform beam and frequency-doubling of interference fringes spatial frequency in self-defocusing photorefractive crystal $LiNbO_3$:Fe by the same experimental setup. Frequency-doubling appears if the nonlinearity of the *c*-axis is bigger than the modulation of the cylindrical lenses, otherwise the modulation instability appears.

1. Introduction

Modulation instability (MI) is a fundamental phenomenon that exists in many nonlinear wave systems in nature. Small perturbations in the amplitude or the phase of optical waves grow exponentially under the combined effects of nonlinearity and diffraction or dispersion due to MI [1,2]. As a result, a broad optical beam or a quasi-continuous wave (quasi-cw) pulse often breaks up into filaments that trend to form trains of solitons, as observed in Kerr-like nonlinear media [3,4]. The phenomena of MI have been identified and studied in various physical systems, such as fluids [5], plasmas [6], nonlinear optics [7] and molecular chains [8] and so on. In nonlinear optics, MI is often considered as a precursor for the formation of stable bright spatial solitons [9]. Conversely, the stable propagation of dark solitons relies on the stability of the constant-intensity background and thus requires the absence of MI [10], so MI and solitons are not a concept. Over the years, MI has been systematically investigated in connection with numerous nonlinear processes, such as in both self-focusing photorefractive nonlinear media [11–17] and self-defocusing photorefractive nonlinear media [18–21]. Traditionally, MI is considered as a coherent process, but later it is observed in partially coherent light [13,15] and fully incoherent white light [16,17,21]. Furthermore, Ref. [22] has studied theoretically and experimentally two-dimensional MI in photorefractive materials and Ref. [23] has studied theoretically modulation instability in two-dimensional partially spatially incoherent systems. But we have not seen any reports referred to frequency-doubling of interference fringes spatial frequency [24] in the modulation instability experimental. In this Letter, we report on our experimental observation of both modulation instability and frequency-doubling of interference fringes spatial frequency in self-defocusing photorefractive crystal $LiNbO_3$:Fe by the same experimental setup. Frequency-doubling appears if the nonlinearity of the *c*-axis is bigger than the modulation of the cylindrical lenses, otherwise the modulation instability appears.

2. Experimental setup and results

2.1. Experimental setup

The experimental setup is shown in Fig. 1. A 50 mW beam that from a He–Ne laser (of $\lambda = 632.8$ nm wavelength) is split into two beams by using the polarizing beam splitter (PBS). One beam which firstly is sent through the $\lambda/2WP$ (the role of the $\lambda/2WP$ is to make sure the used light is the extraordinary polarized light)

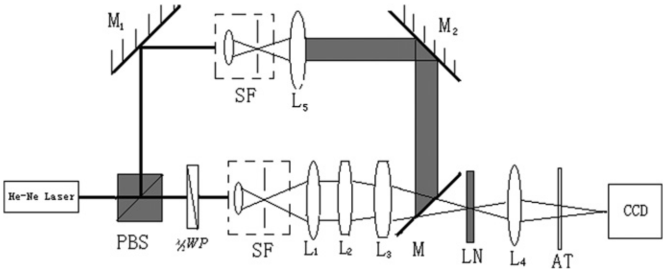

Fig. 1. Experimental setup: PBS (polarizing beam splitter); $\lambda/2WP$ (half-wave plate); SF (spatial filter); L_1, L_5 (lenses); L_2, L_3 (cylindrical lenses); M (permeable semi-reflective mirror); LN ($LiNbO_3$:Fe crystal); L_4 (imaging lens); AT (attenuator); CCD (CCD camera); M_1, M_2 (mirrors).

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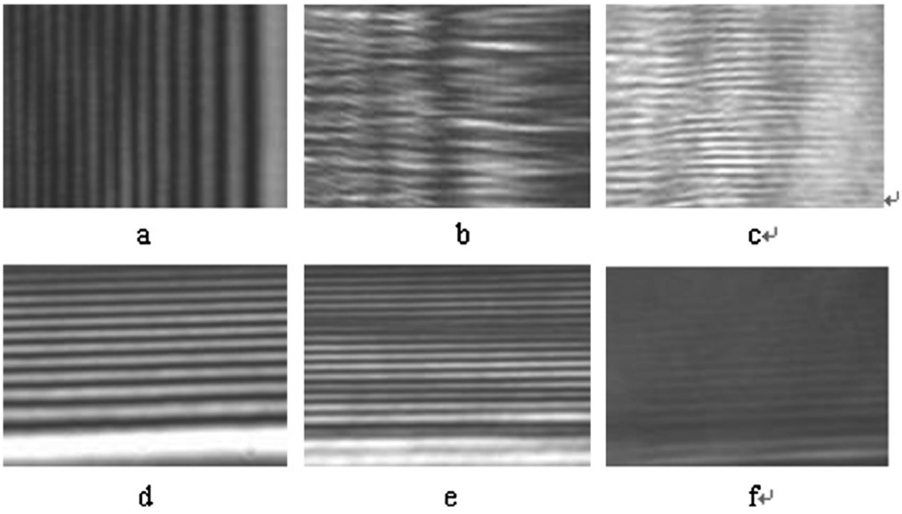

Fig. 2. The intensity distribution when the *c*-axis is vertical.

and then is sent through the SF (spatial filter) becomes uniform light and then it becomes parallel light after it is sent lens L_1 ($f_1 = 225$). And then the parallel light firstly focuses into a rectangular beam whose size is 0.3 mm in the horizontal direction and longer than 1 cm in the vertical direction (it can irradiate the crystal completely in the vertical direction) and then it focuses into a rectangular beam whose size is 0.3 mm in the vertical direction and longer than 1 cm in the horizontal direction after it is sent through a pair of cylindrical lenses ($f_2 = f_3 = 200$). The $LiNbO_3$:Fe crystal (0.03% Fe; the size is $5 \times 10 \times 10\ mm^3$) is placed at the front and back rectangular beam respectively. And the output face of the crystal is imaged onto CCD camera through the imaging lens L_4 ($f_4 = 75$ mm). And attenuator AT is used to weaken light intensity. Another beam which has been expanded and collimated by the SF (spatial filter) and the lens L_5 ($f_5 = 300$ mm) becomes the parallel light and it is as reading light.

2.2. Experimental results

The light that we use is the extraordinary polarized light and its power at the input face of the crystal is 10.3 mW. The size of the beam at the input face of the crystal is 0.3 mm × 1 cm and its propagation distance is 0.5 cm in the crystal. In the following experimental results, all the a, b, c are the intensity distribution when the crystal is placed at the front rectangular beam and d, e, f are the intensity distribution when the crystal is placed at the back rectangular beam. And a and d are the input intensity distribution at the input face of crystal; b and e are the intensity distribution at the output face of the crystal; c and f are the probed intensity distribution at the output face of the crystal with parallel light. We change the direction of the crystalline *c*-axis and with all other conditions unchanged, and the experiment results are as following.

2.2.1. The direction of the *c*-axis is vertical

The input intensity distribution at the input face of crystal is shown as a and d and the fringes are interference fringes. With the increasing of the illumination time, the intensity distribution at the output face is always changing until it reaches the steady state. The MI pattern appears when the crystal is placed at the front rectangular beam and its direction is horizontal. When the crystal is placed at the back rectangular beam, the MI pattern doesn't appear but the number of the interference fringes increases. The experimental results are shown in Fig. 2.

2.2.2. The angle between the *c*-axis and the vertical direction is 30°

The MI pattern appears when the crystal is placed at the front rectangular beam and its direction is also horizontal. When the crystal is placed at the back rectangular beam, the MI pattern doesn't appear either but the number of the interference fringes increases obviously. The experimental results are shown in Fig. 3.

2.2.3. The angle between the *c*-axis and the vertical direction is 45°

When the crystal is placed at the front rectangular beam, the MI pattern appears and its direction is horizontal. When it is placed at the back rectangular beam, the MI pattern also appears and its direction is vertical. No matter it is placed at the front or the back rectangular beam, the number of interference fringes doesn't increase. The experimental results are shown in Fig. 4.

2.2.4. The angle between the *c*-axis and the vertical direction is 60°

When the crystal is placed at the front rectangular beam, the MI pattern doesn't appear but the number of interference fringes increases. When it is placed at the back rectangular beam, the MI pattern appears and its direction is vertical. The experimental results are shown in Fig. 5.

2.2.5. The direction of the *c*-axis is horizontal

When the crystal is placed at the front rectangular beam, the MI pattern doesn't appear either but the number of interference fringes also increases. When it is placed at the back rectangular beam, the MI pattern appears and its direction is vertical. The experimental results are shown in Fig. 6.

3. Discussion

From the experimental results of Figs. 2–6 could we could see that no matter the crystal is placed at the front rectangular beam or the back rectangular beam, the MI pattern appears only when the angle between the short axis of the rectangular beam and the *c*-axis is bigger than or equal to 45° and it always breaks in the direction perpendicular to the direction of the short axis of the rectangular beam, as is shown in Figs. 2b, 3b, 4b, 4e, 5e and 6e. The period of stripes caused by modulation instability is about 10 μm in every condition. When the angle is smaller than 45°, the MI pattern couldn't appear but the number of the interference fringes increases, this can been seen in Figs. 2e, 3e, 5b and 6b.

Cylindrical lenses have the modulation to the beam in one-dimensional, so when the crystal is placed at the front rectangular beam there is modulation in the direction of the short axis.