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Observation of the modulation instability induced by both intrinsic noise and the amplitude mask with periodic lattices

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ABSTRACT

We observe experimentally two types of modulation instabilities induced by both intrinsic noise and the amplitude mask with periodic photonic lattices in self-defocusing media $LiNbO_3$:*Fe* crystal. We find the participation of the amplitude mask accelerates the appearance of the modulation instability. Besides, we observe the modulation instability in two situations when the amplitude mask with periodic photonic lattices is used. One is when the angle between the principle axis of the periodic lattices and *c* axis of the crystal is 0°, and another is 45°. We find periodic photonic lattices have a strong suppression to the further development of the modulation instability in the latter situation.

1. Introduction

Modulation instability (MI) is a universal phenomenon that appears in many nonlinear wave systems in nature. Because of MI, small perturbations in the amplitude or the phase of optical waves can grow exponentially under the combined effects of nonlinearity and diffraction or dispersion [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]. Over the years, MI has been systematically investigated in both self-focusing photorefractive nonlinear media [5–11] and self-defocusing photorefractive nonlinear media [12–15]. And MI is observed not only in nonlinear systems with a perfect degree of spatial and temporal coherence [1,16] but it also can be observed with partially coherent light [7,9] and fully incoherent white light [10,11,15]. There are many reasons that lead to the modulation instability, and some papers about the modulation instability induced by intrinsic noise (such as defects and striations in the crystal) [7,17] or seeding noise from cross-phase-modulation [8] have been reported. Ref. [9] reported the modulation instability of a partially spatially incoherent beam driven by seeding perturbation in self-focusing media strontium barium niobate (SBN). In this letter, we report on the experimental observation of the modulation instability that induced by both intrinsic noise and the amplitude mask with periodic photonic lattices in self-defocusing media $LiNbO_3$:*Fe* crystal. The participation of the amplitude mask accelerates the appearance of the modulation instability. Besides, we observe the modulation instability in two situations when the amplitude mask with periodic photonic lattices is used. One is when the angle between the principle axis of the periodic lattices and *c* axis of the crystal is 0°, and another is 45°. And we find that the photonic lattices have a strong suppression to the further development of the modulation instability in the latter situation.

2. Experimental setup and results

2.1. Experimental setup

The experimental setup is shown in Fig. 1. A bunch of He-Ne laser beam (50 mw) is split into two beams by Polarizing beam splitter (PBS). One beam is expanded and collimated by the Spatial filter (SF) and lens L_1 (f_1 = 105 mm), then it is sent through the amplitude Mask with periodic lattices which is imaged onto the input face of the $LiNbO_3$:*Fe* crystal (doped with 0.03-wt% Fe, $5 \times 10 \times 10\,mm^3$) by the lens L_2 (f_2 = 75 mm). The distance between $LiNbO_3$:*Fe* crystal and the focus of lens L_2 is about 7 mm. The output face of the crystal is imaged onto CCD camera through the imaging lens L_3 (f_3 = 75 mm). And attenuator AT is before CCD. Another beam is expanded and collimated by the SF (Spatial filter) and the lens L_4 (f_4 = 300 mm). And it is as reading light.

2.2. Experimental results

In this paper, the light used in the experiment is the extraordinary polarized light and its power at the input face of the crystal is 15.2 mw. The diameter of the beam at the input face of the crystal is

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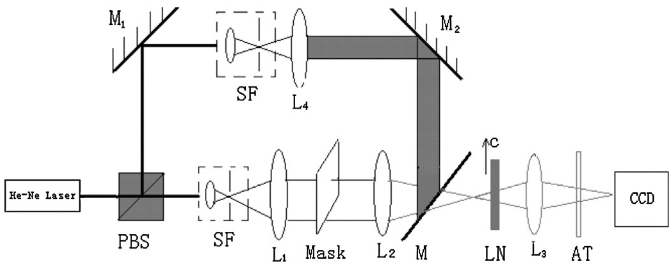

Fig. 1. Experimental setup: Polarizing beam splitter (PBS); Spatial filter (SF); L_1, L_2, L_4 (lenses); M (Permeable semi-reflective mirror); LN($LiNbO_3$:Fe crystal); L_3 (Imaging lens); AT (attenuator); CCD (CCD camera); M_1, M_2 (Mirrors).

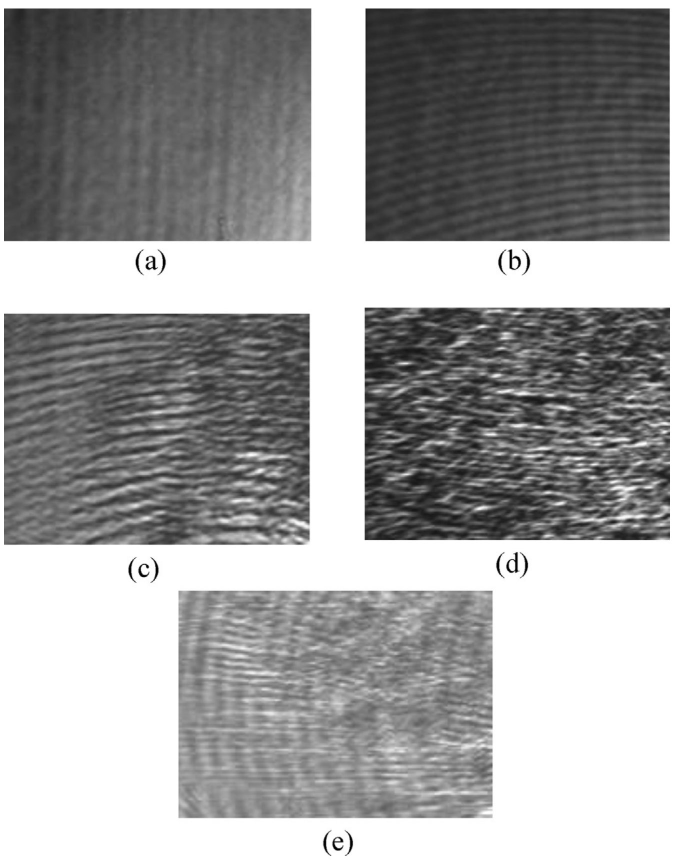

Fig. 2. The intensity distribution pattern of MI that induced by intrinsic noise. (a) Input intensity distribution; (b), (c), and (d) Output intensity distribution when the illumination time is 0, 40, and 130 min respectively; (e) The probed intensity distribution at the output face with the parallel light when the illumination time is 130 min.

3 mm; its propagation distance is 5 mm in the crystal. The direction of the *c* axis of the crystal is vertical (Fig. 1). The typical experiment results are as followings.

2.2.1. The modulation instability induced by intrinsic noise

Firstly, the amplitude Mask with periodic lattices is not used and the crystal is also placed after the focus of lens L_2, and it is 7 mm away from the focus in this situation. The experimental results are shown in Fig. 2. Fig. 2a is the input intensity distribution at the input face of crystal. Fig. 2b is the output intensity distribution at the output face of the crystal when the illumination time $t = 0$. The intensity distribution at the output face of the crystal is changing continuously with the increasing of the illumination time. For example, Fig. 2c is the output intensity distribution at the output face when the illumination time $t = 40$ min. We can see the pattern is not as uniform as the beginning and the interference fringes are cut off. That is to say, the modulation instability appears 40 min later. The pattern reaches the steady state when the illumination time is increased to 130 min (e.g., Fig. 2d), now the interference fringes are completely broken. The pattern will not change any more if the illumination time is continually to be increased. Fig. 2e shows the probed output image with the parallel light when the illumination time is 130 min. We can see the broken filaments in Fig. 2e.

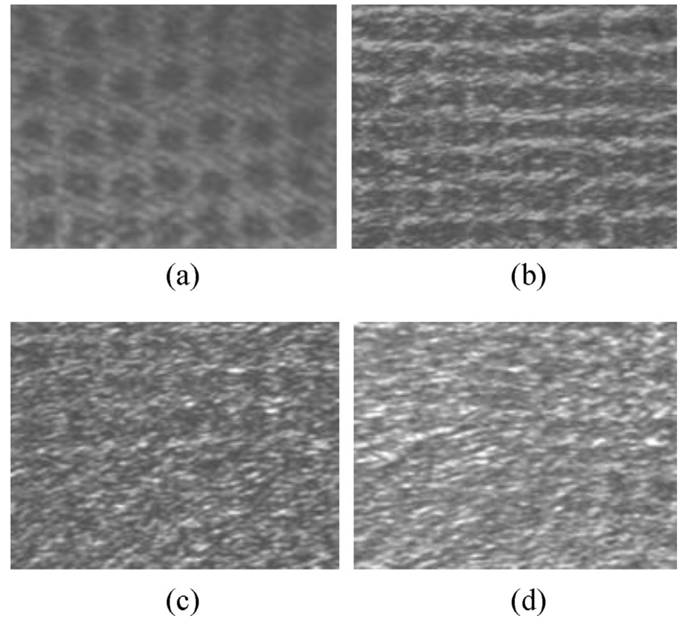

Fig. 3. The intensity distribution pattern of MI that induced by the amplitude mask and the angle between the principle axis of the lattices and *c* axis of the crystal is 0°. (a) Input intensity distribution; (b) and (c) Output intensity distribution when the illumination time is 30 and 90 min respectively; (d) The probed intensity distribution at the output face with the parallel light when the illumination time is 90 min.

2.2.2. The modulation instability induced by the amplitude mask with periodic lattices and the angle between the principle axis of the lattices and c *axis of the crystal is 0°*

The amplitude Mask with periodic lattices is placed between L_1 and L_2 and the angle between the principle axis of the lattices and *c* axis of the crystal is 0°. The diameter of the input dark spot is 20.4 μm and the separation of the adjacent dark spots is 60 μm at the input face of the crystal. Fig. 3a is the input intensity distribution at the input face of the crystal. The modulation instability begins to appear 20 min later at the places that between the dark spot, but the lattices are clear. But the lattices become more and more indistinct with the increasing of the illumination time. For example, Fig. 3b is the intensity distribution at the output face of the crystal when the illumination time $t = 30$ min, although the lattices can be seen yet it is very indistinct. When the illumination time increased to 90 min, the lattices cannot be seen out in the intensity distribution pattern at the output face of the crystal (e.g., Fig. 3c). Fig. 3d is the probed output image with the parallel light when the illumination time is 90 min. We can see the broken filaments in Fig. 3d.

2.2.3. The modulation instability induced by the amplitude mask with periodic lattices and the angle between the principle axis of the lattices and c *axis of the crystal is 45°*

The angle between the principle axis of the lattices and *c* axis of the crystal is changed to 45° and other conditions are unchanged. The experimental results are shown in Fig. 4. Fig. 4a is the input intensity distribution at the input face of crystal. The modulation