Geometrically-tunable self-stabilization effect in Rhodamine 6G

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This paper shows experimental results on geometrically-tunable self-stabilization effect in Rhodamine-6G dye. A crossing-laser-beams scheme has been used in the experiment in order to obtain wide-tuneability of the proposed structure. Obtained results demonstrate radiation power stabilization with up to 175 mW at the input. The proposed self-stabilization scheme can be used as a power-stabilized light source for metrology applications, and integrated circuits with nonlinear optical elements.

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1. Introduction

Recently, lots of applications, which require stable-radiation intensity such as nonlinear photonic crystal circuits, biosensors, metrology, etc., have appeared. In this context, optical limiters [1] and stabilizers have attracted significant attention.

In general, there are two kinds of optical limiters: active, and passive. The former are not very popular since they do not respond fast enough to input pulses; and moreover, they require additional power and electronic control. The latter is the most used for their fast-response and no power supply characteristics. Among passive limiters, the most popular are those based on saturation effects [2], reverse-saturable absorption effect [3,4], thermal lensing, etc.

Particularly, the process of reverse-saturable absorption occurs in material where the excited-state absorption cross section is larger than that of the ground state. Thermal lensing occurs when a narrow laser beam passes through a nearly transparent liquid. A small amount of the incident energy is locally absorbed by the sample along the laser beam producing a local heating condition, which changes the refractive index of the medium in touch with the beam; therefore, the entire medium acts as a lens raising the possibility of limiting the output power.

Some organic materials and compounds (*e.g.* Rhodamine 6G dye) possess properties suitable for optical limiters implementation [5]. However, the chemical properties of organic materials are usually not enough to achieve precise stabilization of the laser radiation power. For this reason, additional power control techniques as direct laser cavity control [6-11] and out of laser cavity control methods [12,13] are used.

The direct laser cavity control method is more expensive and complicated than the external one since it requires the modification of the laser construction. Moreover, external methods allow abstraction from some factors as radiation power shift due to the heating of the laser beam source.

Therefore, in this work an optical power limiter and stabilizer is developed and implemented utilizing a cross-beam self-stabilization scheme on the basis of ethanol solution with Rhodamine-6G dye. The thermal lensing effect is used in this experiment to deflect the Gaussian beam. The proposed technique allows implementing a geometrically-tunable stabilizer that is tested on the laser overheating problem due to an inadequate water cooling system. Obtained results demonstrate that the proposed scheme can be used as a non-trivial geometry for beam self-stabilization.

2. Experimental setup

A schematic diagram and the experimental setup for the proposed optical power limiter are depicted in Fig. 1a and 1b respectively.

The laser Innova I70C @514 nm was used as laser source. The laser beam was splitted into its pump and probe components with measured power ratios at 93.2% and 6% respectively. The probe beam was supposed not to vary significantly the characteristics of the nonlinear medium. The full-width at half-maximum (FWHM) Gaussian beam with a diameter of 2 mm was measured by charge-coupled device (CCD) camera. The two beams cross in the nonlinear medium at a specific position controlled by a shifting table. The nonlinear medium was represented by a cell filled up with 10% ethanol solution of Rhodamine-6G dye. The pump beam was launched along the cell, 2 mm from its side wall where the probe one enters through. The Argon laser radiation was absorbed by the Rhodamine 6G showing an exponentially-decaying trace as can be seen in the Fig. 2b. Therefore, by varying the horizontal displacement of the probe beam, the refraction effect of the lens formed by the pump beam can be varied too.

The radiation intensity was measured by Newport-883-SL photo-detector connected to a Newport 1815-C power meter. The beam entered the photo-detector through a pin hole of 1 mm which allowed cutting away its remaining components. The final beam shape was circular due to the shape of the pin hole. However, cross-field distribution was not measured.

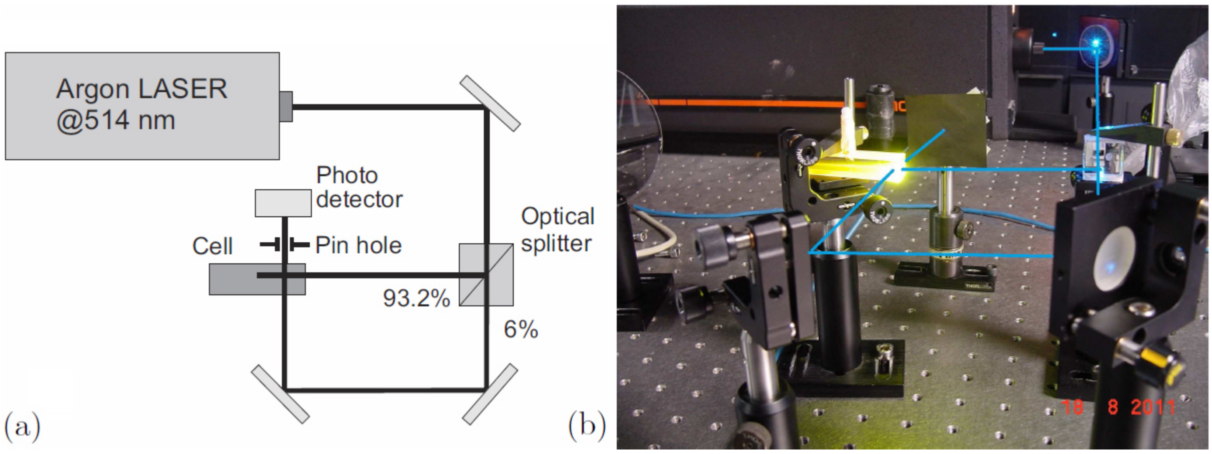

FIGURE 1. Schematic (a) and photo (b) of the experimental setup.

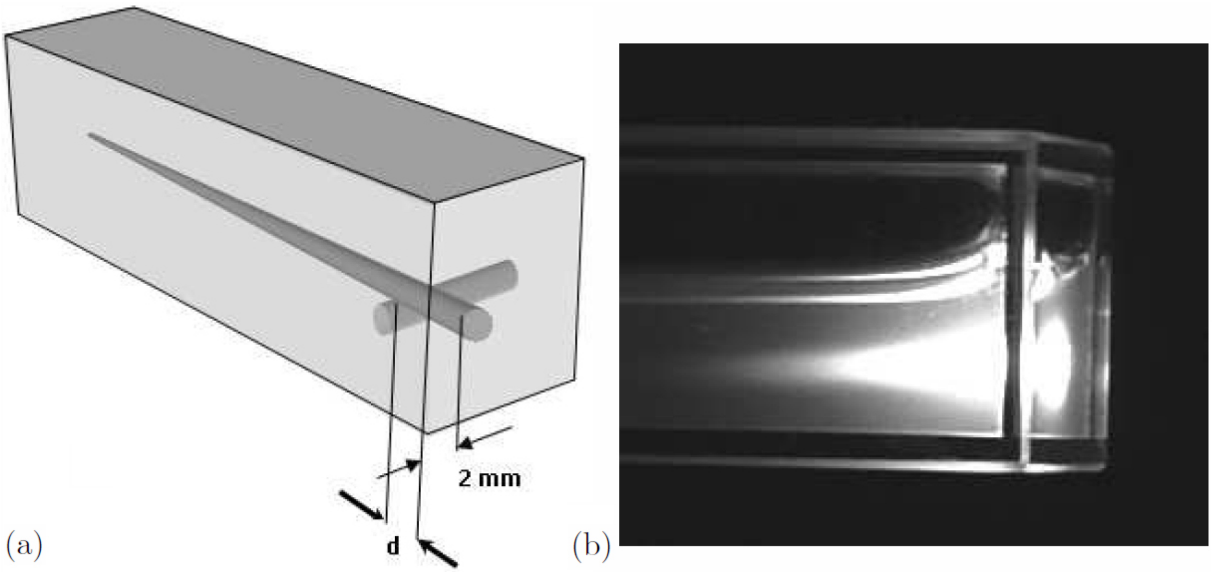

FIGURE 2. The pump and the probe beams in nonlinear liquid (a) and the photo of decaying beam (b).

In Fig. 2a, “d” determined the horizontal shift of the probe beam which was varied from 1 to 10 mm. Its vertical displacement was adjusted using screws on the mirror holder and went from 0 to 0.5 mm.

3. Results and discussion

The main objective of the work was to demonstrate that using geometrical variations of the pump and probe beams positions, it is possible to achieve power stabilization using a self-influence effect of the beam in a nonlinear medium. The expected stabilization characteristics should take form of a horizontal section of the output intensity within some range of the input power values. The quality of the stabilization is determined by two factors, namely, deviation of the output power and its dynamic range (*i.e.* a range of the input power where the output power varies with an allowed deviation).

The ethanol solution of Rhodamine 6G used as negative nonlinear medium in our experiment, possesses two kinds of nonlinearities: electronic, and thermal. In this work the influence of both nonlinearities on the stabilization effect were investigated. To study the electronic effect, short exposition (less than 1/10 of a second) measurements were taken. The radiation power varied form 40 mW to 500 mW. The output power was measured by the power-meter with reaction time of less than 10 ms. The main advantage of the proposed stabilization method is its tuneability; therefore, the probe beam was shifted in the range from 3 mm to 7 mm where the stabilization effect is present as shown in Fig. 3, 4.

Figure 3a depicts the optical limiting due to the electronic effect at different horizontal displacements of the probe beam. In this case, the probe beam crossed the pump one in its center. A weak stabilization effect was observed over 0.25 mW input power; however, it showed to be highly sen-

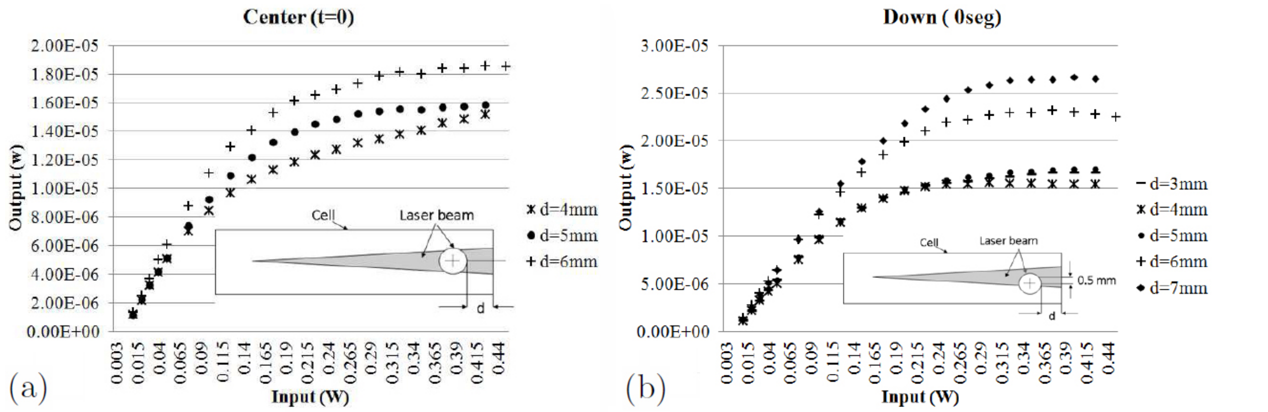

FIGURE 3. Transmission characteristics of the limiter in case of electronic nonlinearity at zero vertical displacement(a) and 0.5 mm displacement (b).

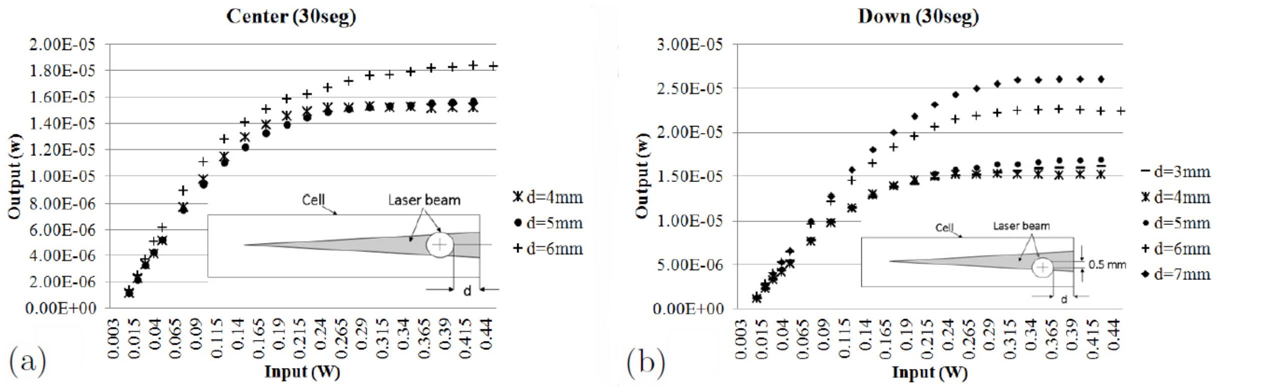

FIGURE 4. Transmission characteristics of the limiter in case of both electronic and thermal nonlinearities at zero vertical displacement(a) and 0.5 mm displacement (b).

sitive to any horizontal displacement d of the probe beam. It appeared only for d = 5 mm and disappeared at any slight variation.

On the other hand, the stabilization obtained with a vertical displacement of 0.5 mm between the pump and probe beams and d = 3 mm (see Fig. 3b), was much better than that when both beams crossed each other at their center. The dynamic range of the output power was 175 mW with a deviation less than 1%. The stabilization did not vary much with the horizontal shifting of the beam. For instance, at 2 mm of horizontal deviation of the probe beam (total displacement of 5 mm), the output radiation was increased by 5% only for an input power of 500 mW. For longer displacements, the stabilization effect was also present; however, the dynamic power range was lower (less than 40 mW). Moreover, for a horizontal displacement larger than 5 mm, the output power was highly-sensitive to the horizontal deviation.

The stabilization effect was also measured taking into account both the electronic and thermal nonlinearity as depicted in Fig. 4. A continuous wave (CW) laser was used taking output power measurements after 30 seconds of exposure when the temperature of the nonlinear medium was settled.

For zero vertical displacement of the probe beam, the stabilization effect appeared closer to expected behavior curves than when just the electronic nonlinearity was present. However, the output power deviation still exceeded 5% within 100 mW.

Analyzing the stabilization effect with 0.5 mm of vertical displacement as depicted in Fig. 4, the obtained measurements were similar to those when just the electronic nonlinearity was present. The stabilization was practically the same

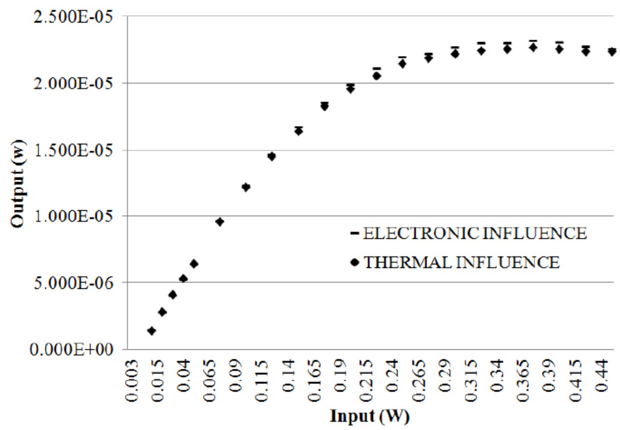

FIGURE 5. Influence of thermal nonlinearity on transmission characteristics.

as well as the dynamic range; although, a slight output power variation appears.

To give a better representation of thermal nonlinearity influence, the stabilization effect under electronic and thermal conditions was measured at the same displacements (vertical displacement 0.5 mm and horizontal one is 6 mm) with different exposition time, and it is depicted in Fig. 5. From this figure, a slight variation of the curve shape can be observed at high power (from 210 mW to 430 mW) due to the thermal nonlinearity, which may introduce an output power error about 7% because of a failure in the laser source precision.

4. Conclusion

In this paper, the stabilization of the output power utilizing the self-influence effect was demonstrated through the variation of geometrical parameters in the beams crossing in a nonlinear medium. The efficiency of proposed stabilization method is relatively low; however, it possesses two major advantages: first, it is highly tuneable by just changing the relative positions of the pump and probe beams, which allows to achieve large dynamic range, high stability or, if necessary, certain limiting shape (even with negative derivative). Second, it works for many nonlinear materials. In this paper, the stabilization effect in Rhodamine 6G dye was demonstrated; however, any nonlinear material possessing either positive or negative nonlinearity produces lens effect at high radiation power and can be used for optical limiting.

Although both the electronic and thermal effects participate in power limiting, the thermal nonlinearity is much slower than the electronic one, and therefore, may not be widely used. In most precision applications pulsed radiation is used; therefore, the electronic nonlinearity is suitable because it provides a fast response time.

The proposed stabilizer was tested utilizing a laser with Gaussian profile beam. However, due to its operating principles, such stabilizer can be easily extended to work with non-Gaussian laser beams.

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