Visualization of intensified IR images in a nonlinear interaction of beams in saturable amplifiers

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A new method for visualizing IR images is proposed, and an implementation is reported. This method makes use of an interaction of light in a medium with two coupled transitions. An intensified image of IR objects has been obtained with a manganese vapor amplifier in green light.

Optical systems with brightness intensifiers[1,2] exhibit several unusual properties[3] because they contain an amplifier operating in a saturation regime. In this letter we discuss some new possibilities that arise for such systems if they use amplifiers which simultaneously have a gain at two or more transitions that are coupled by the upper or lower level. Examples of such systems are the amplifiers using the vapor of barium, lead, and manganese which have been studied experimentally.[1] Saturation of the gain at one of the coupled transitions can lead to a significant modulation of the gain at another. For this reason, the interaction of the fields at the coupled transitions in the active medium can, in principle, be utilized to convert an optical image written as a modulation of the light at one of the transitions into a modulation of the light at the other wavelength.

In this letter we wish to propose pursuing this possibility to visualize IR images. This can be done in the active medium of a pulsed manganese-vapor laser. Figure 1 shows the scheme of the low-lying levels and transitions of the manganese atom. The arrows show lasing transitions in the green and IR parts of the spectrum, which are seen to be coupled by the lower level. Under ordinary conditions, one green line, at 5341 Å, and several IR lines exhibit a large gain.

In the experiments we use a manganese-vapor amplifying laser element with an active length of 70 cm and an inside diameter of 2 cm. The discharge tube operates in a

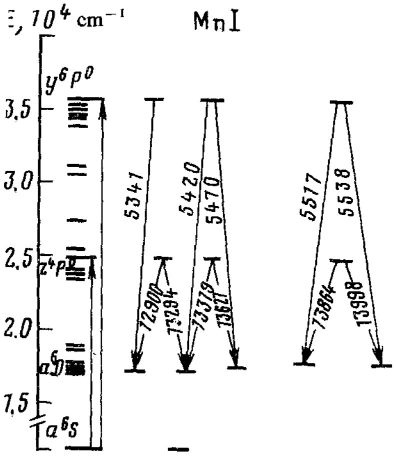

FIG. 1. Low-lying levels and transitions of the manganese atom.

self-heating regime with a neon buffer gas at a pressure of 16–20 torr. The pulse repetition frequency is 2.5 kHz.

The experimental arrangement is shown in Fig. 2. The arrangement is basically similar to the ordinary arrangement of a laser projection microscope.[3]

The light from active medium 1 illuminates object 3 after passing through objective 2. A magnified image of the object, amplified in the active medium, is formed in the light reflected from the object after passing back through objective 2. This image, whose position is monitored by an auxiliary optical system, usually lies inside the active medium. Negative images of object 3 are observed on screen 6 in beams of light propagating toward the object, with the help of a beam splitter 4 and optical system 5; the effect is similar to that observed previously with a copper-vapor amplifier.[4,5] The negative images form, because the intensified image of the object creates a saturation which is nonuniform over the volume of the active medium, thereby causing a spatial modulation of the gain of the medium. The spontaneous-emission beams, which are propagating through the amplifier toward the object, "read" this gain distribution, giving rise to negative images.

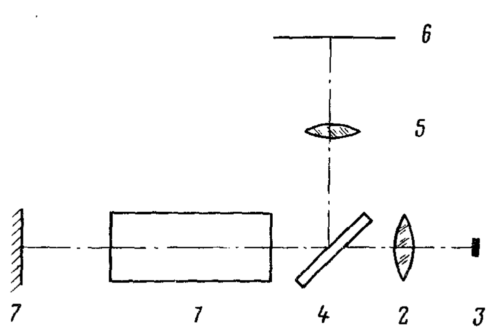

FIG. 2. Optical arrangement of the experiment.

In the present experiments with a manganese-vapor amplifier we observed negative images of an object in both green light and in IR light. In the latter case, rotating fluorescent screens were used for visualization.[6] We then placed a filter which completely cuts out the visible light but which passes IR light between beam splitter 4 and objective 2. In this case, only the IR image of the object was formed in the active medium, and this image caused a spatial modulation of the gain at both the IR line and the coupled green line. As a result, we observed a negative image of the object in green light in the same place as before, although the primary information on the object entered the active medium only in the form of the IR image.

These negative images were obtained in higher quality and were brighter when a mirror 7 was installed beyond the amplifier. In this case the "readout" beams at the green line are increased in power and have a smaller divergence. The placing of a filter which does not pass IR light in front of mirror 7 has no significant effect on the quality of the visualized image, whereas the insertion of a filter that cuts out the green line degrades this image. In most of the experiments, mirror 7 was placed 2 m from the active medium. Reducing this distance degraded the visualized image.

The average power in the negative images in the absence of wavelength selection was about 60 mW in these experiments; the total average power in the positive images of the object was 120 mW.

We used an aluminized plane mirror on whose surface we deposited a black mask

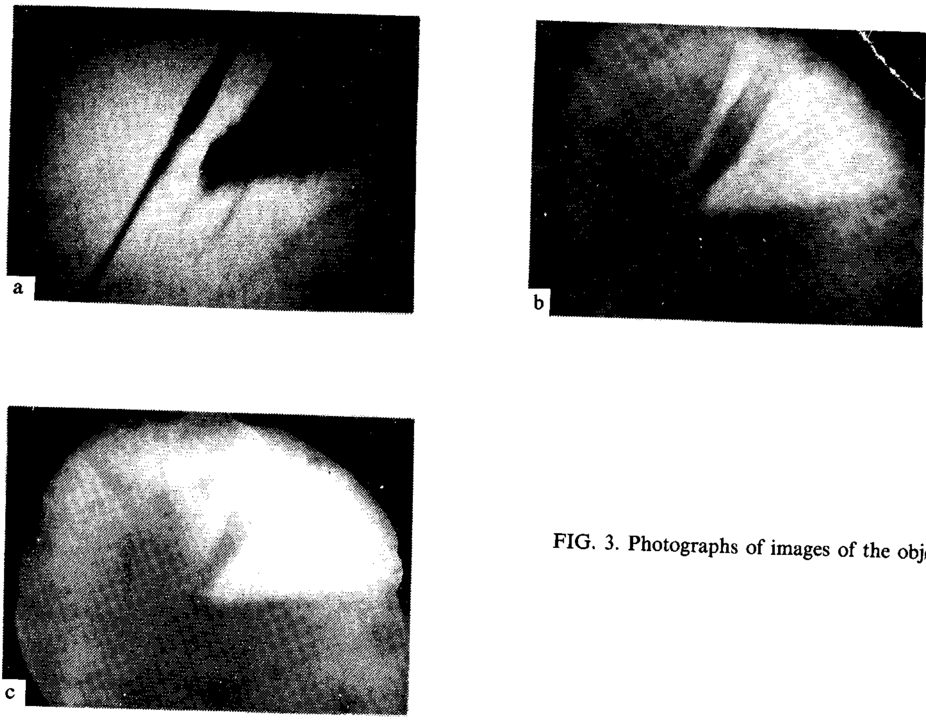

FIG. 3. Photographs of images of the object.

in the form of a segment and a stripe 0.1–0.2 mm in size. Figure 3 shows photographs of images of this mirror. Figure 3a is a positive image in green light, obtained as in an ordinary projection microscope; Fig. 3b shows a negative image of the same object; and Fig. 3c shows a visualized image of the same object. We note that the negative images in the IR and green parts of the spectrum and also the visualized image have identical dimensions and are observed at a 100× magnification under these experimental conditions.

The quality of the images obtained in these experiments is not very high. However, by choosing the appropriate conditions for reading and writing the information in the active medium we could presumably approach an image quality limited only by the particular optical system.

These experiments show that IR images can be visualized quite effectively in the active medium of a pulsed manganese-vapor laser by making use of the interaction in the medium of light beams corresponding to coupled transitions. This visualization method appears to us to have important advantages over other existing methods. The basic advantage is that the visualization occurs in an intensifying medium with a large intensification. It thus becomes possible to achieve a significant power level at the output and to project the visualized images onto large screens. Where necessary, one could use a further intensification in a separate intensifying cell of a manganese-vapor laser.

Since the intensifying element operates in pulses with an intensification of 10–20 ns, and the image brightness is high in each pulse, it would be a simple matter to use a corresponding sweep of the image to achieve high-speed motion-picture photography of microscopic objects, including objects which are opaque in the visible part of the spectrum, with a framing frequency on the order of 1 kHz or possibly even higher. In particular, one could study fast processes through silicon or within objects made of silicon, e.g., elements in microelectronics.

We believe that the use of the method described above for converting optical fields from one part of the spectrum into another can substantially extend the range of application of active optical systems in experimental physics.

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