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Fiber optic pulsed laser holography

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oscillation threshold is determined by direct transition, and the phonon assisted emission follows, if the cavity losses for both emission wavelengths are the same.

Figure 3(b) shows maximum $g_p^{(b)}$ values as a function of the phonon number. Here, the $g_p^{(b)}$ value includes only the effect of the stimulated phonon emission. As the electron-phonon interaction $H_{ep}^{(b)}$ becomes stronger, as is caused by the increase in the phonon temperature, the damping rate for the intermediate electronic state Γ_c increases. The $\hbar\Gamma_c$ value at room temperature is considered to be a few meV,which is more than one order of magnitude smaller than the phonon energy. The T_{if} value in Eq. (3), thus, begins to saturate when the N_q value exceeds about 10. The $g_p^{(b)}$ value, including both the stimulated and spontaneous phonon emission effects, exhibits small dependence on phonon temperature even in small N_q region. Saturated $g_p^{(b)}$ value for each injected carrier density in Fig. 3(b) is smaller than the corresponding direct transition peak gain coefficient by about an order of magnitude. The effect of $g_p^{(b)}$ on QW laser operation is, thus, important, when the cavity loss for direct transition emission is higher than that for the phonon assisted emission by about an order of magnitude.

The phonon assisted emissions were assigned by the emission spectrum data[4] for QW lasers. According to Fig. 2, the photon energy, where the $g_p^{(b)}$ value becomes maximum, increases rapidly, as the pump rate increases. This is in contrast with the direct transition emission, where the emission wavelength keeps a constant value at some pump level and then jumps to the second order transition. The difference comes from the fact that the direct transition requires k conservation for carriers while the phonon assisted transition does not. Strong band filling effect will be observed in the phonon assisted emission spectrum for QW lasers,when the loss spectrum in the cavity is flat.

In the QW structure, a surface mode LO phonon trapped in the quantum well may exist.[6] The procedure similar to the present treatment can be applied to obtain the gain coefficeient $g_p^{(s)}$ assisted by the surface phonons. Saturation number of phonons for $g_p^{(s)}$ is larger than that for $g_p^{(b)}$. But, qualitative behavior for $g_p^{(s)}$ is similar to the present results.

In conclusion, the $g_p^{(b)}$ value strongly saturates with respect to N_q. The saturated $g_p^{(b)}$ is smaller than the corresponding gain coefficient of the direct transition. The photon energy, where the $g_p^{(b)}$ value becomes maximum, increases as the pumping increases. These properties of $g_p^{(b)}$ will explain the features of the reported phonon assisted emission, taking into account other parameters for QW lasers, such as cavity loss spectrum.

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This study demonstrates that pulsed laser illumination may be used to suppress the ambient motion related instabilities associated with the application of coherent multimode optical fiber image bundles to the recording of remote holograms.

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Many new applications of fiber optics for the transmission and manipulation of coherent light have been demonstrated in the areas of holography,[1-5] holographic interferometry,[6-10] and speckle metrology.[11-15] Fiber optics offer several advantages over traditional optical components. From an experimental standpoint, the use of fiber optics can substantially reduce the number of required prisms, mirrors, and lenses, etc., immediately simplifying the laboratory setup. Furthermore, optical fiber systems readily permit the investigator to change the positions of both observation and illumination. Since individual optical fibers and most optical fiber image bundles are of relatively small diameter and quite flexible, they can easily be arranged to illuminate and ob-

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serve remote or enclosed subjects which might otherwise be obscure or inaccessible.

It has been found, however, that multimode optical fiber is not sufficiently stable for most holographic applications unless it is immobilized throughout its length for the duration of any experimental exercise. This is so because bending anywhere along its length produces changes in the modal content of the transmitted light and much of its coherence is lost. As demonstrated in Ref. 8, the use of single mode optical fiber (or SMF) suppresses most of the deleterious effects of fiber motion on holographic stability. That is, the use of individual single mode optical fibers provides stable illumination for both the object and reference beams. Unfortunately, in remote applications this still leaves the "imaging" component (the component through which the object image wave front is transmitted back to the hologram film plane) dependent upon multimode fiber optics because individual single mode optical fibers cannot readily be used to transmit a complex wave front. On the other hand, a coherent bundle of multimode optical fibers (multimode bundle or MMB), such as might be found in a conventional endoscope, will transmit the desired information quite well, provided that it does not experience any significant movement during the time of exposure of the hologram.

In Ref. 5 the authors demonstrated that one way around the stringent stability requirements associated with transmitting holographic information through an MMB is to generate an ultralow frequency (ULF) standing-wave interference fringe field (by combining coherent light from the subject with the reference beam at a small angle) at a remote station and then transmit the image of these fringes back through the MMB to record an ULF hologram. In that experiment, both the object and reference beams were transmitted to the remote location by SMF's. Unfortunately, because of the necessarily restricted bandwidth of such a system, it is difficult to produce holograms that can reconstruct images of much size or complexity.

In order to generate stable holograms of complex subjects using multimode fiber optics, the present study takes the approach of greatly shortening the time of exposure through the use of a pulsed ruby laser as a coherent light source of ultrashort duration ($\sim$20 ns).

Because of the necessarily high energy levels of the coherent light pulses (on the order of joules) and the extremely small SMF core diameter (around 6 μm), it is difficult to use individual single mode optical fibers for any of the light manipulating components of a pulsed laser holographic system. Consequently, it was appropriate to return to the use of multimode optical fiber bundles (MMB's) for the transmission of both the object illumination and reference beams as was done in the earliest studies[6,7] conducted with fiber optics. In the present experiments the object illumination and reference beams were generated by placing the ends of two or more MMB's side by side directly in the 16-mm-diam output beam from the ruby laser. The proper intensity balance was achieved by using one or more MMB's for the object illumination and by the use of a neutral density filter as an attenuator placed in the spread illumination from the output end of the reference beam MMB. In the first of these pulsed ruby laser tests a MMB of 3-mm diam and 50-cm length was paired with another 3-mm-diam MMB of 91-cm length to provide, respectively, the object and reference beam illumination. Both MMB's had effective NA's (numerical apertures) of 0.18. As shown in Fig. 1(a), this configuration was used with an imaging lens between the test object (a tape dispenser) and the hologram plane in order to generate an image plane pulsed ruby hologram. Figure 2(a) shows a white light reconstruction of the resulting hologram recorded with all fiber optics unsupported, except at the ends. Finally, a remote pulsed ruby image plane hologram was recorded using a third MMB of almost a meters length and 10-mm diameter to transmit the image from the object location to the hologram plane, with the reference beam length increased accordingly. As shown in Fig. 1(b), lenses were used to image the object into this MMB at the entrance end and to image the MMB output onto the photographic plate used to record the hologram at the exit end. In order to offset the significant loss of image intensity which occurs while traversing the 10-mm MMB, another 3-mm-diam MMB of 50-cm length was added to the setup [Fig. 1(b)] to increase the intensity of the object illumination and fill in some of the shadows. Figure 2(b) shows a reconstruction of the resulting image plane hologram successfully recorded with all fiber optics, including the 10-mm-diam MMB, supported only at their ends. This represents a complete "remote" configuration in which all information was transmitted to and from the object area via flexible fiber optics.

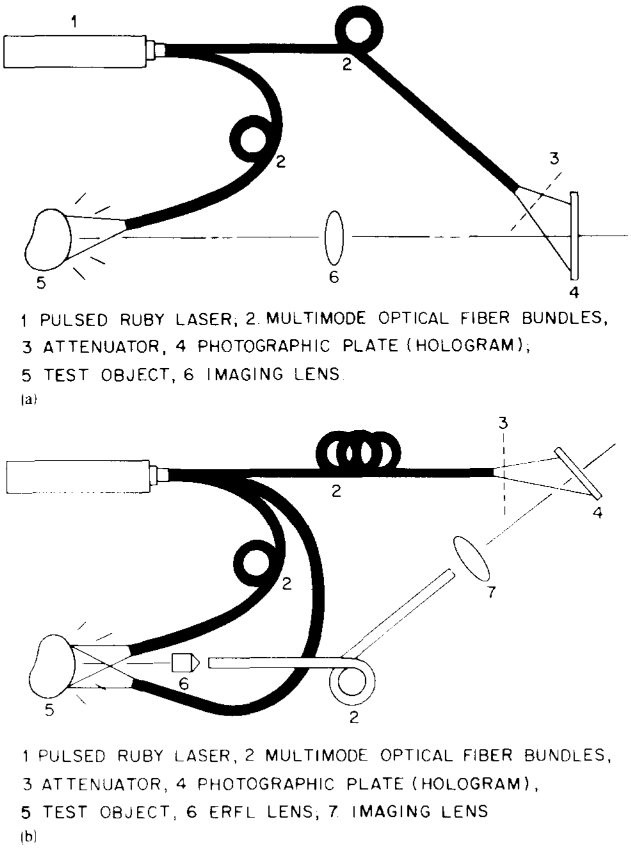

FIG. 1. (a) Schematic of arrangement used to record image plane pulsed ruby holograms using MMB's for object and reference beam illumination. (b) Schematic arrangement used to record remote image plane pulsed ruby holograms using MMB's for the object, reference, and image return beams.

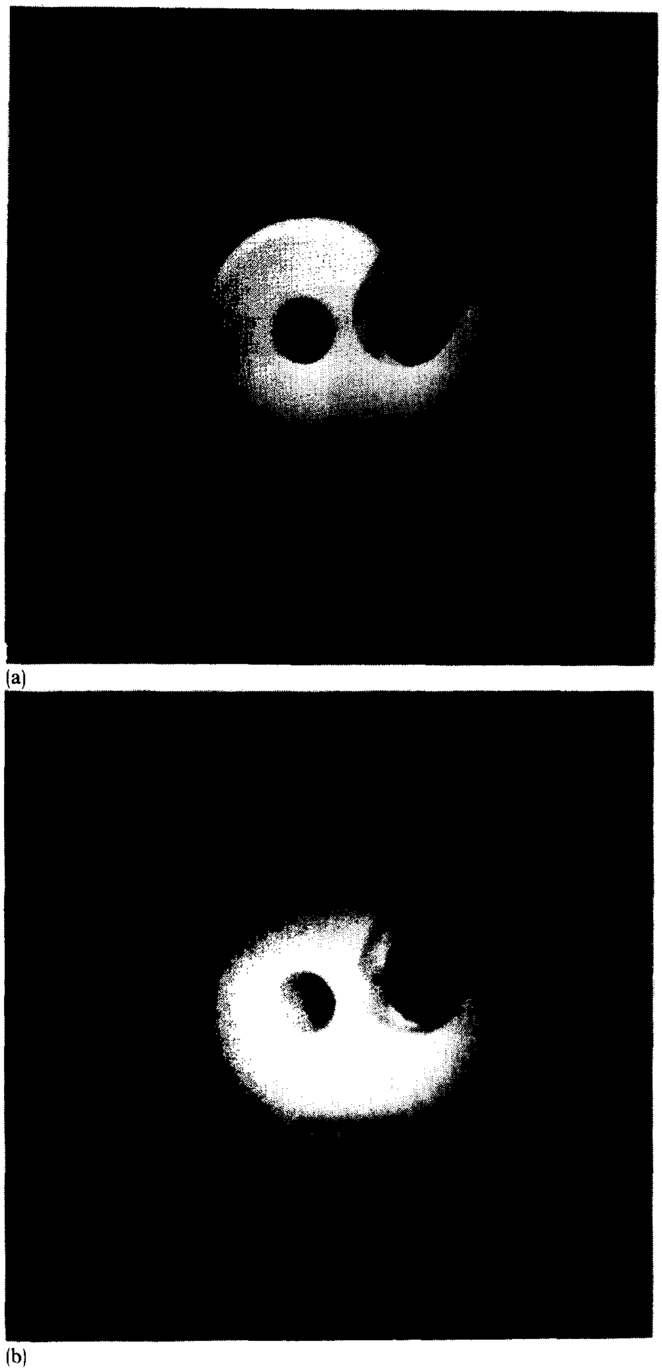

FIG. 2. (a) Reconstruction of an image plane pulsed ruby hologram recorded using MMB's for object and reference beam illumination. (b) Reconstruction of a remote image plane pulsed ruby hologram recorded using MMB's for the object, reference, and image return beams.

In conclusion, it was demonstrated in these experiments that pulsed ruby holograms capable of recording both static and dynamic events can readily be recorded using fiber optic components to manipulate the coherent light pulses. Placing object illumination and reference beam bundles directly in the unspread beam from the ruby laser eliminates the need for a continuous wave alignment laser and beam splitter. Fiber bundles safely and conveniently capture the high energy light pulses, and permit simplified experimental setups with reduced need for rigid mounts and isolation tables. Both conventional, image plane and remote image plane holograms can be recorded by this technique, and even at operating levels on the order of joules the MMB's are quite capable of handling the light pulses without destroying the coherence needed to generate holograms.

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