Observation of a two-frequency resonant hologram from excited sodium atoms

I. S. Grigor'ev, A. F. Semerok, V. A. Firsov, and A. V. Chankin

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The diffraction of a cw laser beam in resonance with the $3P_{1/2}$–$3S_{1/2}$ transition by a grating hologram of excited sodium atoms has been detected in a beam of sodium atoms. The grating is formed by light resonant with the $3P_{3/2}$–$3S_{1/2}$ transition.

The observation of grating holograms consisting of excited states of the particles of a medium with discrete energy levels was reported in Refs. 1–12. The holograms were written, and the reconstruction was carried out, by light in resonance with one of the transitions between the ground state and an excited state.

There is considerable interest in studying the possibility of writing a resonant hologram on one transition of a medium and carrying out reconstruction from this hologram by means of light in resonance with a second transition, sharing a level with the first. The medium in which this two-frequency resonant hologram is to be produced must have two excited energy levels to which radiative transitions are possible. If the hologram lies in the XY plane, and if we denote the writing and readout beams by $I_1(x,y)$ and $I_2(x,y)$, then we can easily find the following result by solving the system of kinetic equations for the populations of levels 1, 2, and 3 for low intensities of the readout beam $(I_1\sigma_{12}\tau_2/\hbar\omega_1 \ll 1)$:

$$n_1-n_3=n_0[f_1(I_2,\sigma_{13},\tau_3,\omega_2,\sigma_{12},\tau_2,\omega_1)I_1(x,y)+f_2(I_2,\sigma_{13},\tau_3,\omega_2)]; \quad (1)$$

here n_1, n_2, and n_3 are the populations of levels 1, 2, and 3; $n_0 = n_1 + n_2 + n_3$; σ_{12} and σ_{13} are the cross sections for the transitions at the frequencies ω_1 and ω_2; and τ_3 and τ_2 are the lifetimes of states 3 and 2.

It can be seen from expression (1) that under the condition $I_2(x,y) = \text{const}$ the difference between the populations of levels 1 and 3 linearly follows the intensity distribution in the interference pattern of the writing waves; i.e., a hologram should also be written on the 1–3 transition. For this reason, the light with frequency ω_2 reconstructs an image written by the light at frequency ω_1.

In the present experiments we have produced a two-frequency resonant hologram in a beam of sodium atoms. The hologram is written on the $3P_{3/2}$–$3S_{1/2}$ $(F=2)$ transition, while readout is taken on the $3P_{1/2}$–$3S_{1/2}$ $(F=2)$ transition. The beam from a *cw* dye laser (rhodamine 6G; $\lambda = 588.995$ nm) with a spectral width ~ 1 MHz is expanded by a telescope (9:1) and sent through an attenuator to a Michelson interferometer, where it is split into two beams of identical intensity, which propagate at a small angle with respect to each other. Both beams are passed into a vacuum chamber, where they are incident on a beam of sodium atoms. The angle at which the beams converge and the thickness (l) of the vapor slab satisfy the condition for the writing of thin holograms.

The frequency stability of the laser output is monitored by means of an interferometer with a free-dispersion interval of 50 MHz. Figure 1 is a photograph of a grating hologram produced by the *cw* laser beam in the beam of sodium atoms. Self-diffraction of the writing beam can be observed on a screen placed at the focus of the optical system.

To determine the diffraction efficiency of the grating, we direct a third light beam to it, at a small angle with respect to the writing beams. This third beam is a small fraction of the output from the writing laser, whose polarization plane has been rotated 90°. The intensity in the first diffraction orders of the writing beam is observed to reach a maximum when the optical thickness of the vapor slab is $n\sigma l \sim 1$ and when the intensities of the writing beams are on the order of I_s (the saturation intensity for this transition). As the intensity of the writing beams is increased, higher diffraction orders appear.

To estimate the contributions from amplitude modulation and phase modulation, we tune the output from the writing laser near the absorption lines of hyperfine components of the $3P_{3/2}$–$3S_{1/2}$ transition. It follows from Fig. 2 that the maximum in the first order of self-diffraction does

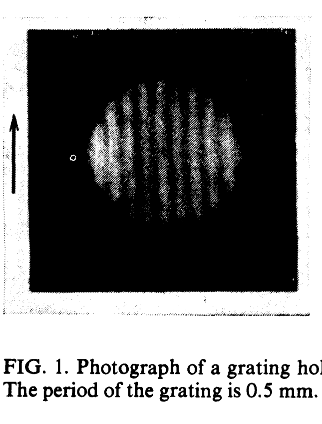

FIG. 1. Photograph of a grating hologram in a vapor of sodium atoms. The period of the grating is 0.5 mm.

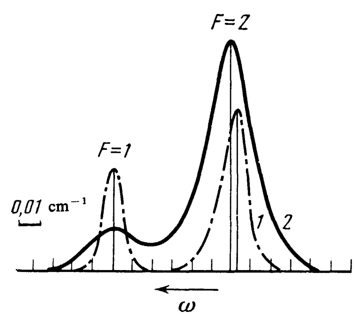

FIG. 2. 1—Intensity of the light in the first order of self-diffraction versus the laser output frequency; 2—absorption line of the beam of sodium atoms. The light intensity at an antinode is ~ 20 mW/cm^2; the grating period is 0.5 mm; and we have $n\sigma l \sim 1$ at the absorption maximum corresponding to the $3P_{3/2}$–$3S_{1/2}$ $(F=2)$ transition. The horizontal scale is 0.01 cm^{-1}/div.

not coincide with the absorption maximum for the writing beam; this result is evidence that both amplitude modulation and phase modulation are occurring.

The optimum conditions found for the writing of a single-frequency resonant hologram were reproduced in an experiment on two-frequency resonant holography. The beam from a second *cw* dye laser with a spectral width ~ 50 MHz was tuned to the wavelength (589.592 nm) of the $3P_{1/2}$–$3S_{1/2}$ $(F=2)$ transition, expanded by a telescope (5:1), and directed to the grating produced by the first laser. When the frequency of the second laser was exactly equal to the frequency of the $3P_{1/2}$–$3S_{1/2}$ $(F=2)$ transition, we observed diffraction of the beam of this laser.

The two-frequency resonant hologram produced in these experiments shows that by choosing media appropriately one might be able to visualize images written in the IR, UV, or x-ray regions of the spectrum and to produce multicolor holographic images by using suitable mixtures.

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