SUPERLUMINAL AND ULTRA-SLOW LIGHT PROPAGATION IN ROOM-TEMPERATURE SOLIDS

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We have observed ultra-slow light propagation (57 m/s) in ruby and superluminal (Ö800 m/s) light propagation in alexandrite at room temperature. The modifed light speed results from the rapid variation in refractive index associated with spectral holes and antiholes produced by the process of coherent population oscillations.

In recent years there has been great interest in techniques that can lead to a modification of the propagation velocity of light pulses through optical materials [1,2]. Interest stems both from the intrinsic interest in the ability to control the velocity of light over large ranges and from the potential for applications such as controllable delay lines, optical data storage devices, optical memories, and devices for quantum information.

Much of this recent work has made use of the process [3] of electromagnetically induced transparency (EIT) to modify the absorptive and refractive properties of a material both to produce the good transparency needed to propagate pulses over long distances and to produce a rapid variation of refractive index needed to produce slow light. We have recently introduced a new method for achieving ultra-slow light propagation [4]. Our method produces slow light in room temperature solids. Like EIT, our method makes use of the concept of quantum coherence, but uses a different effect known as coherent population oscillations [5,6]. In particular, we apply pump and probe fields to our ruby crystal, and the population of ground-state chromium ions is induced to oscillate coherently at the resulting beat frequency. These oscillations lead to a decreased absorption of the probe beam, and consequently (by the Kramers-Kronig relations) to a steep spectral variation of the refractive index with a positive slope. Since the group index is given by $n_g = n + \omega\, dn / d\omega$, this process produces a large positive value of the group index. We have also studied light propagation in alexandrite [7], which at certain wavelengths acts as an inverse saturable absorber. In this case, coherent population oscillations lead to increased absorption of the probe beam and consequently a steep variation of the refractive index with negative slope and thus a negative value of the group

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index. The conditions under which each of these effects can occur are summarized in the energy level diagrams of Fig. 1.

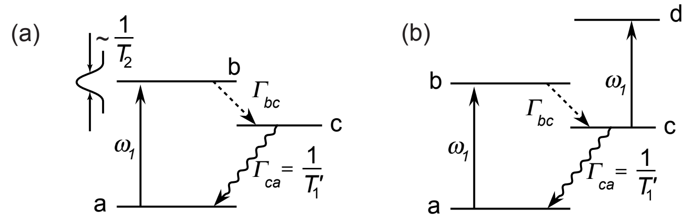

Figure 1. (a) Energy level diagram of a saturable absorber such as ruby. (b) Energy-level diagram of an inverse saturable absorber, such as alexandrite at certain wavelengths. Inverse saturable absorption occurs when the absorption cross section for the c–d transition exceeds that of the a–b transition.

The experimental setup used to observe these effects is shown in Fig. 2. Because the spectral hole in ruby and the spectral antihole in alexandrite are so narrow (37 Hz in ruby and 612 Hz in alexandrite), we use a modulation technique to observe these features. In particular, we pass the laser beam through an electrooptic amplitude modulator to synthesize the probe beam as frequency sidebands to the pump frequency, and we then determine the group velocity be determining how fast the modulated waveform propagates.

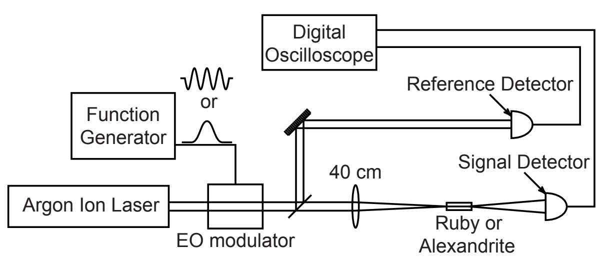

Figure 2. Experimental setup.

Figure 3 shows some of our laboratory results. The inset on the left shows typical data for ruby [4]; in this particular case the output waveform is seen to trail the input waveform by 612 microseconds. The main plot shows how the measured time delay depends on modulation frequency for two values of the pump intensity. The maximum time delay of 1.2 ms that we observe corresponds to a group velocity of 57 m/s and to a group index of 5×10^6. Our results for the case of alexandrite [7] are shown on the right of Fig. 3. In this case we observe a negative value of the group delay for a wide range of modulation frequencies.

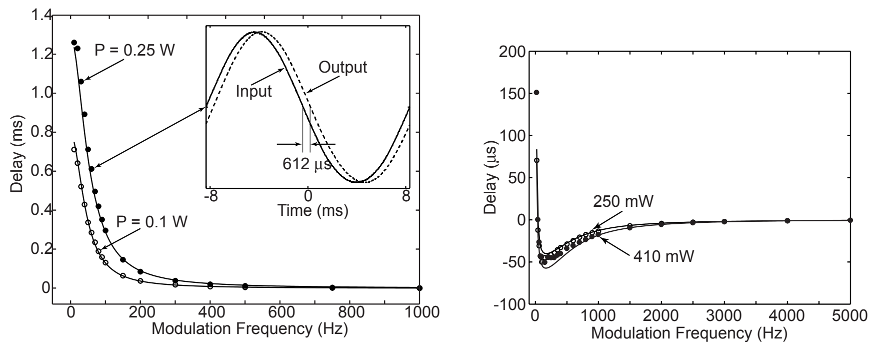

Figure 3. Left: Variation of the measured time delay for ruby with modulation frequency. The inset shows typical data. Right: Variation of the time delay with modulation frequency for alexandrite. For a broad range of frequencies the time delay is negative, implying superluminal propagation.

In summary, we have demonstrated a new technique based on coherent population oscillations for producing slow and fast light propagation in room temperature solids

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