All-Optical Switching in a Coherent Atomic Medium

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Electromagnetically induced transparency (EIT) is interesting in its own right and also possesses certain qualities—namely reduced absorption and large dispersion near resonance—that make it promising for future device applications.[1] Enhanced optical nonlinearities are present near EIT conditions, which allows for many useful and interesting applications. One of the most important elements of all-optical computation and information processing is fast, all-optical switching. With the increased Kerr nonlinearity that exists near EIT conditions, we have recently demonstrated that all-optical switching can be realized in an atomic medium within an optical ring cavity.

Kerr nonlinearity is a phenomenological process by which the index of refraction of a medium is modified by the intensity of the light passing through the medium. We have directly measured the Kerr nonlinear index of refraction as a function of frequency detuning from resonance of a probe beam in rubidium vapor[2] and showed that EIT significantly modifies the Kerr nonlinear index near resonance [Fig. 1(a)]. We find the Kerr nonlinear index depends strongly on several experimentally controllable parameters: the probe and coupling laser frequency detunings and the coupling optical power.[3] With only small frequency detunings (<10 MHz) the Kerr nonlinear index can change from a large positive value of ~7 x $10^6 cm^2/W$ to almost nothing, or it can change sign. This kind of sensitive control in nonlinearity allowed us to observe bistability and dynamic instability at low thresholds.[4]

With such controllable nonlinearity, we also achieved all-optical switching in a three-level atomic medium (a vapor cell) by switching between two distinct steady-state intensities inside an optical cavity **(Author, is the three-level atomic medium a vapor cell or is it inside a vapor cell? If the first, sentence can remain as is. Otherwise the word "in" should be added, as in "(in a vapor cell)".** A probe beam enters the cavity through a concave mirror and a coupling beam enters via a polarizing beam splitter. As the probe beam intensity is scanned up and down using an electro-optic modulator, the cavity output undergoes a clear hysterisis pattern [see Fig. 1(c)] indicative of optical bistability, because of the EIT-enhanced Kerr nonlinearity. Because the nonlinearity is controllable, we can switch between low and high steady-state intensities at the cavity input power of 0.39 mW **(Author, does sentence as edited convey your meaning?)**. We accomplish this by switching the frequency detuning of the coupling beam between two values (24 MHz separation) through electro-optic modulation [Fig. 1(e)] near EIT resonance conditions. The cavity output power is switched back and forth between low and high steady-state values with a switching ratio of ~30:1 as the frequency of the coupling laser is modulated [see Fig. 1(d); from Ref. 5] **(Author, if the [5] does not signify that Fig. 1(d) is from Ref. 5, please clarify the meaning of this superscript. Thanks.)** This is the first experimental demonstration of all-optical frequency-to-amplitude switching in such a system. The current switching speed is limited by the speed of our frequency modulation (~200 kHz).

We have developed an efficient, all-optical switching device by taking advantage of the sensitive controllability of EIT-enhanced Kerr nonlinearity near resonance in three-level rubidium atoms. While the current device has not been optimized, we see it as a proof-of-principle demonstration that will enable greater advances in the field of all-optical communication and information processing. With the advent of EIT in solid-state materials, it will be possible to realize the practical applications of such all-optical switching.

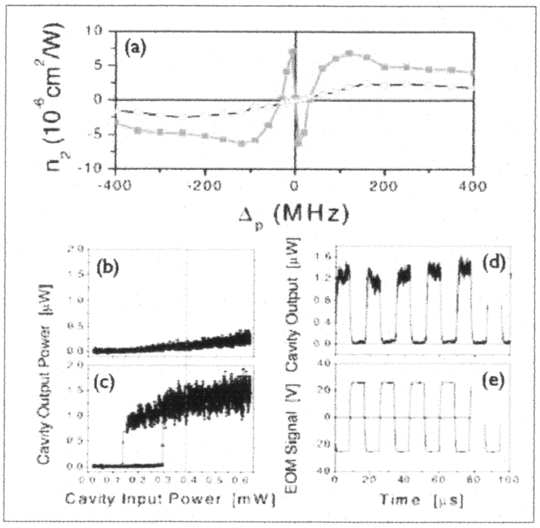

Figure 1. (a): Kerr-nonlinear index of refraction versus frequency detuning of the probe beam near EIT conditions. (b) and (c): Cavity transmission intensity versus cavity input power curves for two different coupling frequencies separated by 24 MHz. Dotted line indicates probe power used for all-optical switch. (d) "On" and "Off" switching states of cavity output intensity. (e) Electro-optic modulation signal switching the coupling laser frequencies between two values.

References

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