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[invited]

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Exploring carrier dynamics in semiconductors for slow light

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Abstract: We give an overview of recent results on slow and fast light in active semiconductor waveguides. The cases of coherent population oscillations as well as electromagnetically induced transparency are covered, emphasizing the physics and fundamental limitations.
(190.5970) Semiconductor nonlinear optics including MQW; (250.5980) Semiconductor optical amplifiers

The experimental demonstrations of slowing down [1] and even stopping light in atomic gasses have led to a significant interest in exploring the physics and applications of this phenomenon. Practical applications, e.g. within microwave photonics [2] and optical communications, favour a technology which allows cheap and compact devices with potential for integration and recent results on semiconductor waveguides indicate a strong potential [3-11].

Fig. 1 illustrates the level schemes and corresponding susceptibilities for two schemes that may be used to realise light slow-down in semiconductors, i.e., electromagnetically induced transparency (EIT) [3,10] and coherent population oscillations (CPO) [12]. For a recent review of CPO effects in semiconductors please refer to [11].

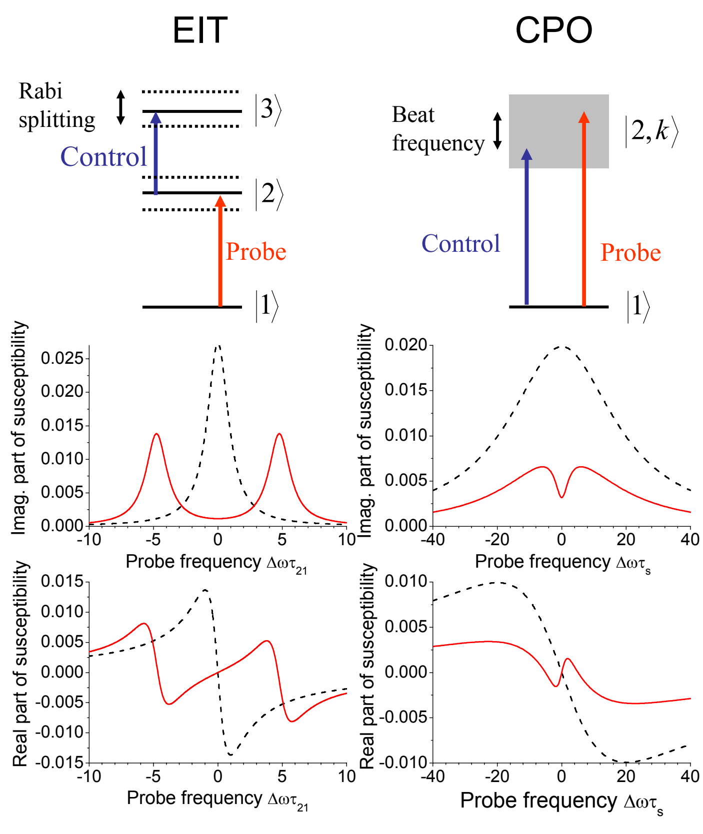

Figure 1. Illustration of level diagrams and typical calculated examples of susceptibilities for electromagnetically induced transparency (EIT, left column) and coherent population oscillations (CPO, right column) versus detuning frequency. The level schemes (upper row) illustrate the choice of control and probe photon energies, $\hbar\omega_{co}$ and $\hbar\omega_{pr}$, for the two schemes of excitation. Below, the imaginary and real parts of the susceptibilities are depicted, with dashed lines showing the susceptibilities for zero control signal. The probe frequency is normalized with respect to the 2-1 dephasing time for the EIT scheme and with respect to the carrier lifetime for the CPO scheme.

The realisation of EIT requires a discrete level structure, as found in semiconductor quantum dots. In this case a strong control beam dresses the levels 2 and 3, thereby strongly modifying the absorption and index experienced by the probe beam. Relying on quantum mechanical coherence among the levels, EIT is very susceptible to dephasing processes, which are known to be very strong in semiconductors. In the talk we will discuss the fundamental aspects of EIT in semiconductors, in particular emphasizing the role of dephasing processes and the prospects of short pulse light slow-down [10].

CPO based light-speed control is much more readily achieved since it does not rely on quantum mechanical coherence among levels and therefore it is not impeded by dephasing processes. It has been show that the combination of gain and absorber sections in a single monolithically integrated device allows to realise phase shifts up to about 150 degrees at gigahertz frequencies [7]. These devices rely on the exploration of carrier dynamics in the various sections, which, e.g., make it possible to tailor the frequency response within a certain bandwidth to realize a true time delay for applications in phased array antennas [8]. Another, recently demonstrated, way of enhancing the performance of phase shifters based on slow and fast light effects is to perform optical filtering before detection [13]. By blocking one of the sidebands one may thus benefit from the refractive index dynamics inside the structure to further enhance the phase shift and the bandwidth. In the talk we will outline some of the possibilities and challenges for practical applications of slow and fast light in semiconductor waveguides, in particular within the field of microwave photonics.

Acknowledgments

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References

[1] L.V. Hau et al. “Light speed reduction to 17 meters per second in an ultracold atomic gas”, Nature **397**, pp. 594-598 (1999).

[2] J. Capmany, B. Ortega, D. Pastor and S. Sales, “Discrete-time optical processing of microwave signals”. IEEE/OSA J. Lightwave Technol. **25**, no. 2, pp. 702-723 (2005).

[3] C. Chang-Hasnain and S.-L. Chuang, “Slow and Fast Light in Semiconductor Quantum-Well and Quantum-Dot Devices.” J. Lightwave Technol. **24**, 4642-4654 (2006).

[4] J. Mørk, R. Kjær, M. van der Poel and K. Yvind, “Slow light in a semiconductor waveguide at gigahertz frequencies.” Opt. Express, **13**, 8136-8145 (2005).

[5] A. Uskov et al., “Slow and superluminal light in semiconductor optical amplifiers”, Electronics Letters **41**, 922-924 (2005).

[6] H. Su et al., "Variable optical delay using population oscillation and four-wave-mixing in semiconductor optical amplifiers", Optics Express, **14**, 4800-4807 (2006)

[7] F. Öhman, K. Yvind, and J. Mørk, “Voltage-controlled slow light in an integrated semiconductor structure with net gain”, Opt. Express, **14**, pp. 9955-9962, (2006).

[8] F. Öhman, et al., "Slow light in a semiconductor waveguide for true-time delay applications in microwave photonics", IEEE Photonics Technology Letters, **19**, 1145-1147 (2007).

[9] P. Kondratko et al., “Slow-to-fast light using absorption to gain switching in quantum-well semiconductor optical amplifier”, Optics Express, **15**, 9963-9969 (2007).

[10] P. Kaer Nielsen, H. Thyrrestrup, J. Mørk, and B. Tromborg, “Numerical investigation of electromagnetically induced transparency in a quantum dot structure, Optics Express, **15**, pp. 6396-6408, May 2007.

[11] J. Mørk, F. Öhman, M. van der Poel, Y. Chen, P. Lunnemann, and K. Yvind, ”Slow and fast light: Controlling the speed of light using semiconductor waveguides,” Laser & Photon. Rev., 1–15 (2008).

[12] M. Bigelow et al., “Observation of ultraslow light propagation in a ruby crystal at room temperature”, Phys. Rev. Lett. **90**, 113903-1-4 (2003).

[13] W. Xue, Y. Chen, F. Öhman, S. Sales, and J. Mørk, “Enhancing Light Slow-Down in Semiconductor Optical Amplifiers by Optical Filtering”, Opt. Lett., vol. 33, 1084-1086, 2008.