Reversible sub-ps optical switching of GaAs-AlAs microcavities

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Abstract

We present ultrafast pump-probe reflectivity measurements on microcavities with a cavity resonance at telecom wavelengths. We demonstrate ultimate fast decrease and recovery of the cavity resonance due to the instantaneous electronic Kerr effect.

1. Introduction

Switches are widely applied and necessary ingredients in modulation and computation. Recent progress on photonic integrated circuits [1] promises to overtake boundaries set by con-ventional switching. Therefore, ultrafast switching of photonic cavities is crucial as it allows the capture or release on demand of tunable photons [2, 3, 4], which is relevant to on-chip communication and to high-speed miniature lasers. Ultrafast switching would also permit the cavity quantum electrodynamical manipulation of coupled cavity-emitter systems [5, 6, 7] in real-time. Switching photonic nanostructures is achieved by changing the refractive index of the con-stituent materials. To date, the switching speed has been limited by material properties (see Ref. [8]), but not by optical considerations. Here, we demonstrate the ultimate fast switching of the resonance of an asymmetric cavity in the well-known GaAs-AlAs system in the telecom wavelength range.

2. Experimental

We have performed our experiments on a planar microcavity grown by means of molecular-beam epitaxy. The sample consists of a λ-thick GaAs layer ($\mathrm{d} = 376$ nm) sandwiched between two Bragg stacks consisting of 7 and 19 pairs of $\lambda/4$-thick layers of nominally pure GaAs ($\mathrm{d_{GaAs}} = 94$ nm) or AlAs ($\mathrm{d_{AlAs}} = 110$ nm). The cavity was designed such that the resonance occurs at λ_0 = 1280 nm in the Original (O) telecom band. Measuring the linewidth of the cavity resonance we obtained a quality factor $\mathrm{Q} = 320 \pm 30$ corresponding to a cavity storage time of $\tau_{cav} = 0.3$ ps. To perform Kerr-switching on a semiconductor microcavity, we have built a set-up, consisting of two independently tunable optical parametric amplifiers (OPA,Topas) that are the sources of the pump and probe beams [9]. The pump beam can be tuned down to 4200 cm^{-1} (2400 nm) and the probe beam is tuned to cavity resonance at 7810 cm^{-1} (1280 nm). Under these conditions, we solely pump GaAs (the refractive index change of AlAs is much smaller and can be neglected here). The pump beam has a larger Gaussian focus (75 μm full width at half maximum) than the probe beam (28 μm), to ensure that only the central flat part of

ISBN 978-952-67611-0-7

the pump focus is probed and that the probed region is homogeneously pumped. The OPAs have pulse durations $\tau_P = 0.12 \pm 0.01$ ps. The delay Δt between pump and probe pulse is set by a delay stage with a resolution of 0.01 ps. A versatile measurement scheme was developed to compensate for possible pulse-to-pulse variations in the output of our laser

3. Results

Figure 1 shows the transient reflectivity versus the frequency versus the pump-probe delay. The white line shows the resonance frequency of the cavity. There are three regions of interest visible. In region I (long before the pump pulse arrives) the resonance frequency is at its unswitched value. We see that in region II the resonance frequency shifts to the red by nearly one linewidth. We conclude from the shift to a lower frequency that the refractive index is increased by $0.1\ \%$, which corresponds to a positive Kerr coefficient for GaAs. Since at large pump-probe delays (region III) the resonance shifts back to its

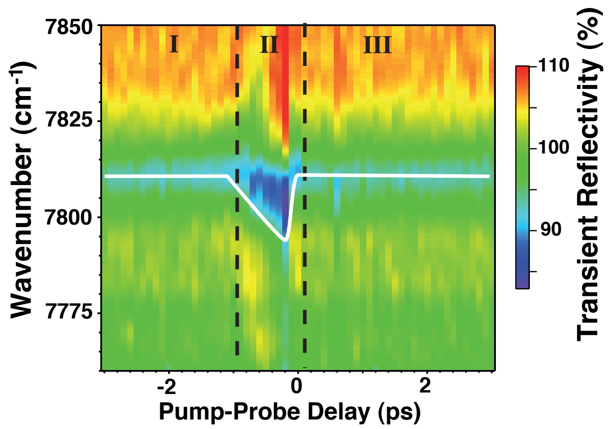

Fig. 1: Reflectivity as a function of frequency and pump-probe delay. At pump-probe coincidence a red shift of the cavity resonance is observed.

original value, we conclude that we do not excite any free carriers in the system. The latter would lead to a much slower decrease in refractive index and a blue-shift of the resonance, respectively, see Ref. [10].

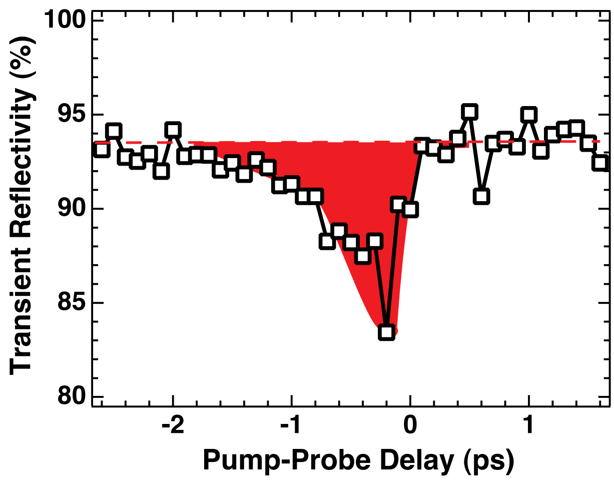

Fig. 2: Transient reflectivity at the unswitched resonance frequency as function of delay. A reversible switch in reflectivity is observed at pump-probe coincidence.

Figure 2 shows the transient reflectivity of the unswitched resonance frequency as a function of the pump-probe delay. It is visible that the transient reflectivity quickly changes from high to low (at pump-probe overlap) and back to high, within $1.5\ ps$. This decrease is a result of the change of the refractive index of GaAs not only in the cavity but also in the mirrors, which leads to a higher contrast in the Bragg stack.

4. Conclusion

Here, we demonstrated the ultimate fast switching of the resonance of an asymmetric cavity in the well-known GaAs-AlAs system in the telecom wavelength range using the instantaneously fast electronic Kerr effect. We observe that the speed of the switching – both on and off – is then only limited by the dynamics of the light in our cavity [11]. Our results pave the way to real-time quantum electrodynamics and ultimate fast data modulation.

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