Attosecond photocarrier excitation in III-V semiconductors

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Abstract: Using transient absorption spectroscopy, we investigate laser-induced attosecond electron dynamics in III-V semiconductors. We find a complex interplay between *intra*- and *inter*-band transitions in the transient response. Our findings are supported by *ab-initio* calculations.

The understanding and control of carrier dynamics in bulk solids opens the path for the development of the next generation of ultrafast electronics. Recently, electron excitations induced by light has been resolved on the sub-femtosecond timescale in semiconductors [1,2] and dielectrics [3,4] using attosecond transient absorption spectroscopy (ATAS). In these works, pump photons with energies smaller than the bandgap were used. In contrast, we present a detailed study of ultrafast electron dynamics induced by *resonant* absorption in GaAs, a direct band gap semiconductor [5]. In particular, we unravel the distinct roles of the *intra*- and *inter*-band transitions during the light-matter interaction.

In our experiment, a semiconductor membrane is pumped with an infrared laser pulse and probed subsequently with a delayed extreme-ultraviolet (XUV) single attosecond pulse. Here, the *resonant* pump can excite carriers either directly from the valence band (VB) into the conduction band (CB, *inter*-band transition) or accelerate them within the individual bands (*intra*-band motion). The XUV pulse probes the modified carrier distribution around the band gap (Fig. 1(a)). Using state-of-the-art first-principle calculations, the experimentally observed XUV absorption modulation could be fully reproduced (Fig. 1(b) and (c)).

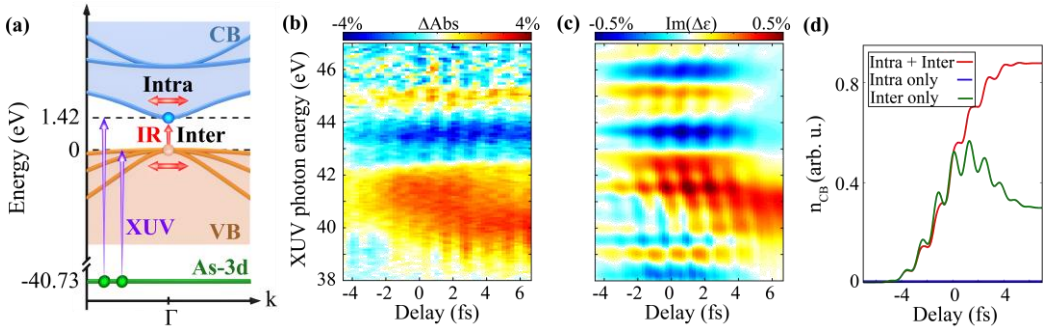

Fig. 1 (a) Illustration of *intra*- and *inter*-band transitions induced by a *resonant* infrared (IR) pump pulse in GaAs. **(b), (c)** Measured and *ab-initio* simulated transient absorption spectroscopy traces. **(d)** Calculated CB population for different limits involving only one or both excitation mechanisms.

Given the *resonant* pump condition, *inter*-band transitions were expected to dominate the transient ultrafast optical response of the material. We could show however that *intra*-band motion plays a non-negligible role and can even dominate. Based on this finding, we performed a detailed study of the interplay of the two mechanisms for different excitation and bandgap configurations with regards to the injection efficiency of carriers from the VB into the CB [6]. Interestingly, we found that the injection can be significantly enhanced by *intra*-band motion, even though no carriers can be excited into the CB solely by itself (Fig. 1(d)).

Finally, we extended our experimental investigation to $Al_{0.8}Ga_{0.2}As$, which has a bandgap larger than the pump energy. Due to the *non-resonant* excitation, the *intra*-band transition is expected to play an even more dominant role in the optical response of the sample.

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