# Ultrafast pump-probe spectroscopy of 1D van der Waals heterostructures

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A novel class of 1D nanomaterials was created by building radial heterostructures, such as wafer scale, free-standing thin films of $MoS_2$ nanotubes grown outside BN nanotubes and carbon nanotubes [1, 2]. We examined the optoelectronic properties of atomically thin 1D van der Waals heterostructures comprising the single-walled carbon nanotubes wrapped by insulating BN layers and $MoS_2$ outer layers ($MoS_2$@BN@CNT) as presented in Fig. 1b. Here we will present the equilibrium properties of such materials (through optical absorption, Raman scattering, photoluminescence, FTIR and THz spectroscopy studies), and the dynamical properties of excitons and free charges (via optical pump-optical probe, and optical pump – THz probe spectroscopy).

The radial heterostructure showed a unique THz photoconductivity (Fig. 1c) that dynamically changed from anomalous (positive ΔT/T, corresponding to negative photoconductivity) to normal (positive), driven by mobile free charges in the $MoS_2$ with a mobility comparable to high-quality 2D $MoS_2$. In addition, optical pump–white light probe spectroscopy revealed that excitons are the primary initial photoproduct in the $MoS_2$ NT of the present vdW heterostructure. We discuss the co-existence of free charges and excitons in the heterostructure.

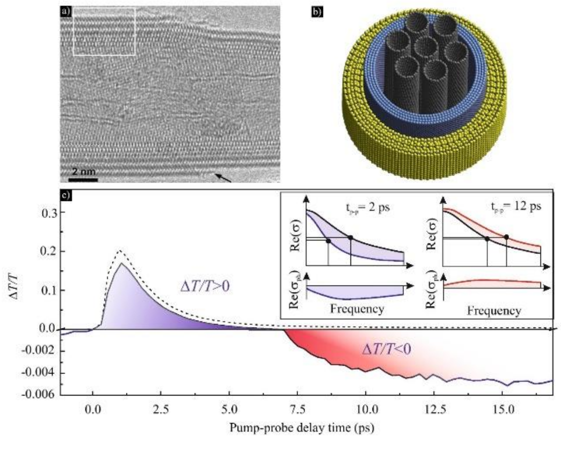


**Figure 1**: a) Atomic STEM ADF image of C@BN@$MoS_2$ NT heterostructure; b) model of C@BN@$MoS_2$ NT heterostructure; c) The switch from ΔT/T>0 at early times to ΔT/T<0.

**References:**

**1.** M. G. Burdanova *et al.* Nano Lett. **20** 3560 (2020).

**2.** R. Xiang *et al.*, Science **367** 537 (2020).