Department of Electrical and Computer Engineering
University of Rochester, Rochester, NY
Ph.D. Public Defense

Friday, August 10, 2012
2:00 PM
Computer Studies Building 426

Time-resolved characterization of non-equilibrium carrier dynamics in Gallium based III-V materials and devices

Jie Zhang

Supervised by
Professor Roman Sobolewski

Ga-based III-V materials, such as, GaAs, GaN and AlGaN, have wide-range applications in the fields of high-speed, high-temperature, high-power and high-frequency electronic and optoelectronic devices, due to their unique physical properties. This thesis is devoted to the time-resolved characterization of ultrafast, nonequilibrium carrier and phonon dynamics in Ga-based III-V materials and their devices. I present my studies of coherent acoustic phonons (CAPs) and nonlinear optical (NLO) process in GaN and AlGaN single crystals, as well as the ultrafast characterization of epitaxially-grown GaAs meso-structured photodetectors (PDs) and self-switching diodes (SSDs) operating as novel THz emitters and photon sensors.

Studies of CAPs and NLO properties in III-Nitrides were accomplished using a femtosecond time-resolved pump-probe spectroscopy. We have experimentally investigated the generation, propagation and detection mechanisms of CAPs and, with the two-side CAPs detection scheme, the intrinsic phonon lifetime was measured to be 80 ns in GaN single crystals at room temperature. The NLO properties of AlGaN single crystals were studied by means of a multi-photon absorption (MPA) technique. My research shows that AlGaN exhibits a large nonlinear correlation factor, with a strong, 310-fs-wide correlation peak. Furthermore, our analysis of the correlation peak amplitude on the pump wavelength allowed us to demonstrate that its spectral dependence agreed very well with the Sheik-Bahae and Hutchings theory for the two photon absorption (TPA) process. The latter indicates that the TPA process in AlGaN sample in our experiment consisting of one pump and one SHG probe photons.

I further report optical characterization of a novel PD device based on epitaxially-grown, single crystal GaAs. Our freestanding PD features an extremely low dark current of only 2×10^{-9} A and responsivity of 4.4 mA/W at 30 V. Its photon detection efficiency is ~ 7%. The time-domain electro-optical sampling (EOS) measurement results show that the PD has an ultrafast ~ 310 fs photoresponse, corresponding to a bandwidth of 1.4 THz. With a double-pulse optical excitation, the PD was tested for successful operation under ~ 1 THz clock rate. All the above properties make it a device-of-choice for the future high-speed, high repetition rate, low power consumption optoelectronic application.

GaAs-based SSDs have already shown their unique performance in microwave harvest and are predicted to be ahigh-efficient THz emitters. We present here, for the first time, the time-resolved transient THz radiation signal generated by a photo-excited and biased SSD. The signal exhibits ~730 fs FWHM, what corresponds to a 0.5 THz bandwidth burst.