

Matrix elements and excitonic effects in the direct gap absorption of semiconductors

Stefan Zollner

Department of Physics, New Mexico State University, Las Cruces, NM

Most common semiconductors have a p-bonding valence band and an s-antibonding conduction band. This band structure leads to strong interband transitions at the direct band gap, which can be observed using spectroscopic ellipsometry. The magnitude of this absorption can be predicted from the optical dipole matrix element, which is well known from k.p theory and the effective conduction and valence band masses (cyclotron resonance experiments). Due to the Coulomb interaction between the photogenerated electron and hole, excitonic effects must be considered. This theory works very well for the direct absorption of germanium.

At high temperatures and for small gap semiconductors like InSb, one must consider the conduction band nonparabolicity, the k-dependence of the optical dipole matrix element, the temperature dependence of the effective masses, the thermal occupation of the electron and valence bands (Pauli blocking), and the screening of the excitonic (Sommerfeld) enhancement by thermally excited electron-hole pairs. The calculations to explain our experimental data for the temperature-dependent dielectric function of InSb are not yet complete, but I will show results for the conduction band nonparabolicity and the chemical potential and free carrier concentration of intrinsic InSb as a function of temperature.

In inverted (gapless) semiconductors like alpha-tin, we can also observe strong intervalence band transitions in the infrared optical constants. These transitions are governed by the same principles as for InSb.

This research was supported in part by the Air Force Research Laboratory Sensors Directorate, through the Air Force Office of Scientific Research Summer Faculty Fellowship Program, Contract Numbers FA8750-15-3-6003, FA9550-15-0001 and FA9550-20-F-0005. It was also supported by the Air Force Office of Scientific Research (AFOSR) under Award No. FA9550-20-1-0135 and by the National Science Foundation under Award No. DMR-2235447.

Dr. Stefan Zollner received his Ph.D. at the Universität Stuttgart (Germany) in 1991 with research performed at the Max-Planck-Institute for Solid State Research advised by Professor Manuel Cardona. After a postdoctoral appointment at the IBM Research Division in Yorktown Heights, NY, and a five-year stint as an Assistant Professor at Iowa State University in Ames, IA, with a joint appointment at the Ames Laboratory, he worked for 15 years in the semiconductor industry for Motorola, Freescale Semiconductors, and IBM in Mesa, AZ, Tempe, AZ, Austin, TX, and East Fishkill, NY. Since 2010, he has been the Head of the Department of Physics at New Mexico State University in Las Cruces, NM. His research on the optical properties of semiconductors, insulators, and metals using temperature-dependent spectroscopic ellipsometry has been supported by AFOSR, ARO, DOE, and NSF.