Terahertz emission from photoexcited carbon nanostructures

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One of the recent trends in bridging the terahertz (THz) gap in electromagnetic spectrum is to use carbon-based nanostructures [1]. Following our earlier work on narrow-gap carbon nanotubes and graphene nanoribbons [2], as well as graphene bipolar waveguides [3] and double quantum wells [4], we consider terahertz (THz) transitions in two other types of nanocarbons – carbynes and cyclocarbons.

The technology of synthesizing carbynes (also known as linear acetylenic or polyynic carbons) has evolved rapidly over the last few years [5], with stable long chains deposited on substrates now being a reality. A prominent feature of long polyyne chains (chains with two alternating non-equal bonds) is the presence of topologically protected mid-gap edge states. For a finite-length chain the two edge states form an even and odd combination with the energy gap proportional to the edge-state overlap due to tunneling. These split states of different parity support strong dipole transitions. We have shown [6] that for long enough (over 18 atoms) carbyne chains, the energy separation between the HOMO and LUMO molecular orbitals formed by the edge states corresponds to the THz frequency range. There are several other allowed optical transitions in this system which can be used to maintain inversion of population required for THz lasing.

Another recent achievement in nanocarbon technology is a demonstration of controlled synthesis of cyclocarbons, in particular cyclo[18]carbon allotrope [7]. The properties of cyclocarbons in an external electric field differ drastically depending on the parity of the number of dimers in a polyyne ring. This is a direct consequence of breaking the inversion symmetry in a ring consisting of an odd number of dimers, including the famous C18. Our estimates [8] show that adding just one extra carbon dimer to C16 is equivalent to placing this molecule in an external magnetic field of 10^4 T. For an odd-dimer cyclocarbon, as a result of the inversion symmetry absence, an experimentally attainable electric field should open a tunable gap between otherwise degenerate states leading to two states with allowed dipole transitions between them in the THz range. A population inversion can be achieved again using optical pumping.

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