

Electrons: A Strange Particle with an Intelligent Spirit - as seen from IR and THz Spectroscopy

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The electron has been investigated thoroughly and applied widely since it was discovered by J. J. Thomson in 1897 [1]. The motion of electrons as well as their manipulation and control, especially in semiconductors, have been fundamental problems in all modern scientific and technologic endeavor. In early stages of modern physics and electronics, classical and linear motions of electrons in vacuum under external fields were understood by classical electromagnetism and Newtonian dynamics. Devices based on the classical motion of electrons in vacuum tubes via Coulomb and Lorentz forces were developed in the early part of the last century. A revolutionary leap in technology occurred when electron behavior in the solid state environment, especially in semiconductors was understood by laws of quantum mechanics. The effective control of the number and the motion of electrons in a semiconductor solid state environment by manipulating material properties, *i.e.* energy band structures, dielectric index, effective mass m^* , doping *etc.*, as well as manipulating the device structures such as p-n junction, hetero-structures, and all types of nanostructures, has led to the modern information technology capabilities we know today.

The scientific and technological developments were so quick and smooth that we would believe we knew electronic behavior and could control electron motion completely! But we want to show another side of the coin: that the electron motion can be highly non-linear, that is, chaotic in certain conditions and a new understanding has been added to our general knowledge of electrons. By means of THz and Infrared spectroscopy we have observed its spectral features, including the so called Quasi-Landau Resonance (QLR) [2,3] as well as non-Poisson distribution of energy levels for impurity electrons, and their quasi-orbit of the chaotic motion can be directly explored through fitting of the observed spectra.

Our experimental observation of quantum chaotic dynamics of orbital electrons is actually based on a hydrogen-like Rydberg atom located inside a semiconductor, that is, a solid state environment. This system corresponds to the anisotropic diamagnetic Kepler problem. Coherent interference of electron wave packets traveling closed semi-classical orbits led to quasi-Landau resonances (QLR) [2,3] which were directly observed near the ionization threshold. The measurements were done on a phosphorus donor in Si by infrared thermal ionization spectroscopy under magnetic fields. Extending the Gutzwiller [4] trace formula to solid state environment with large relative dielectric constant and anisotropic effective mass tensor m_{ij} , we have identified the classical periodic orbits that give rise to observed quasi-Landau resonances. The measured spectra and theoretical calculations provide clear evidence of quantum chaotic dynamics of electrons in the solid state systems near an impurity atom [5]. Furthermore it is observed that the energy level distribution nearby the threshold follows a composed function composed of Poisson and Gaussian functions, differing from textbook descriptions and manifesting as an electronic system that is in a chaotic regime [6].

References

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