Why are weakly coupled semiconductor superlattices chaotic?

Holger T. Grahn[1]

[1] *Paul-Drude-Institut für Festörperelektronik,*
Leibniz-Institut im Forschungsverbund Berlin e. V.,
Hausvogteiplatz 5-7, 10117 Berlin, GERMANY

A weakly coupled semiconductor superlattice represents an almost ideal one-dimensional nonlinear dynamical system with a large number of degrees of freedom, the nonlinearity of which is due to sequential resonant tunneling between adjacent quantum wells. In 1974, this type of superlattice was found to exhibit stationary electric-field domains [1], i.e., an inhomogeneous distribution of the applied electric field with a region of small and a second region of large field strength. In the 1990s, the first indications of instabilities such as current self-oscillations in a weakly coupled GaAs/AlAs superlattice were reported [2]. The oscillatory behavior is attributed to the localized, oscillatory motion of the domain boundary, which separates the high from the low electric-field domain. At the same time, spatiotemporal chaos was predicted to occur in n-doped semiconductor superlattices with sequential resonant tunneling as their main charge transport mechanism [3]. Chaos is expected, when the undamped current self-oscillations are driven by means of an external signal. Shortly after, spontaneous, i.e., undriven, chaos was observed in a weakly coupled GaAs/AlAs superlattice at low temperatures [4]. Five years ago, spontaneous chaotic and quasi-periodic current self-oscillations were observed at room temperature in GaAs/(Al,Ga)As superlattices using an Al content of 45% [5], which results in the largest direct barrier for this materials system. Based on these weakly coupled GaAs/$Ga_{0.55}Al_{0.45}$As superlattices operating at room temperature, an all-electronic true random number generator has been demonstrated [6]. The achievable bit rates of up to 80 Gbit/s are very competitive, being about two orders of magnitude larger than typical bit rates for currently available all-electronic true random number generators. Very recently, the synchronization of chaos based on room temperature spontaneous chaotic current self-oscillations in a weakly coupled GaAs/$Ga_{0.55}Al_{0.45}$As superlattice has been established as a useful building block for various tasks in secure communications [7]. Finally, last year, noise-enhanced chaos was reported for a doped, weakly coupled GaAs/$Al_{0.45}Ga_{0.55}$As superlattice at room temperature [8]. It was observed in experiments as well as simulation results of nonlinear transport based on a discrete tunneling model. When the noise amplitude is increased, spontaneous chaotic current oscillations appear over a wider bias voltage range.

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