Chaotic current self-oscillations in weakly coupled semiconductor superlattices for true random number generation

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A weakly coupled semiconductor superlattice (SSL) represents an almost ideal one-dimensional nonlinear dynamical system with a large number of degrees of freedom. The strong nonlinearity in a doped, weakly coupled SSL originates from sequential resonant tunneling between adjacent quantum wells. Growth imperfections and various fluctuations of the layer thicknesses, electron density, energy levels, and inter-well coupling transform a weakly coupled SSL into a complex nonlinear system, in which the electron transport is strongly dissipative. During the last two decades, a great richness of nonlinear transport behavior has been observed in weakly coupled SSLs, including the formation of stationary electric-field domains, periodic as well as quasi-period current self-oscillations, and even driven as well as undriven chaos [1]. The oscillatory behavior is attributed to the localized, oscillatory motion of the domain boundary, which separates the high from the low electric-field domain. All experimental observations of these phenomena were confined to temperatures below 100 K until very recently, when spontaneous chaotic [2] and quasi-periodic [3] current self-oscillations were observed at room temperature in GaAs/(Al,Ga)As SLs using an Al content of 45%. This Al content results in the largest direct barrier for the GaAs/(Al,Ga)As materials system.
Based on these weakly coupled GaAs/$Ga_{0.55}Al_{0.45}As$ SLs operating at room temperature, an all-electronic true random number generator (TRNG) has been demonstrated [4]. The spontaneous chaotic current self-oscillations with large amplitudes characterized by a bandwidth of several hundred MHz do not require external feedback or conversion to an electronic signal prior to digitization. The method is robust and insensitive to external perturbations, and its fully electronic implementation suggests scalability and minimal post processing in comparison to existing optical implementations. 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 TRNGs. Even more recently, the synchronization of chaos based on room temperature spontaneous chaotic current self-oscillations in a weakly coupled GaAs/$Ga_{0.55}Al_{0.45}As$ SL has been demonstrated as a useful building block for various tasks in secure communications, including a source of all-electronic ultrafast TRNG [5]. The emergence of several types of chaos synchronization has been experimentally demonstrated, in particular leader-laggard, face-to-face, and zero-lag synchronization in networks of coupled SSLs consisting of unidirectional and mutual coupling as well as self-feedback coupling. The realization of chaotic SSLs without external feedback and the synchronization among different structured SSLs open up the possibility for advanced secure multi-user communication methods based on large networks of coupled SSLs.

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