[Invited Talk] Stochastic Resonance in Molecular Network Systems

Takuya Matsumoto

Department of Chemistry, Graduate School of Science, Osaka University
1-1 Machikaneyama-cho, Toyonaka, Osaka 560-0043, Japan
Email: matsumoto-t@chem.sci.osaka-u.ac.jp

In recent decades, studies on the electronic properties and functions of single molecules have made significant advances through the utilization of break junctions and scanning tunneling microscopy. Single molecular transistors have been demonstrated using nano-gap electrodes; however, such investigations have not directly led to actual molecular-scale electronic devices, due to the lack of effective technologies for wiring between molecules. Beyond single molecular transistors, the exploration of device architecture is a central issue in molecular-scale electronics. One of the attractive directions is the realization of neural networks that utilize self-assembled molecular systems. The most simple neuron communication model is represented by a step function that corresponds to neuron firing. Such threshold characteristics should yield stochastic resonance (SR), which is the basis of information processes in living organisms including nerve circuits in the human brain. SR enhances signal detection by superimposing noise. It has found in nonlinear response system, as typical example of sensors of living organisms and the neural network of the brain, and it is used in artificial systems for visual processing and associative functions.

The physical requirement can be realized by Coulomb blockade (CB) phenomena, where the current-voltage (I-V) characteristics show a step function due to the charging energy in the Coulomb island. The electronic configuration in Coulomb island is almost the same as molecular redox system where it is presumed that the tunneling or hopping site approximates a Coulomb island on the molecular scale. The parallelism means that a self-assembled molecular array can be described by the well-developed theory of the CB model, and is therefore expected to exhibit a neural network behavior.

The devices was fabricated with DNA scaffold for the formation of the molecular network. After the molecular network is fixed on the SiO_2 substrate, gold (Au) nano-gap electrodes (ca. 50 nm) are fabricated on the molecular network using a top-contact configuration by angled incidence deposition under vacuum [1].

From the analogue between a molecular network and a Coulomb island network, it is expected that CB network model would be suitable to interpret the $I-V$ curves with V_{th}. The $I-V$ characteristic of the CB network is well represented; the model is expressed as $I \propto \{(V/V_{th})-1\}^{\zeta}$, where I, V, V_{th}, and ζ are the current, bias voltage, threshold voltage, and index for the number of electronic conduction paths, respectively. The obtained $\zeta = 2.5$ is in good agreement with those ($2.2 < \zeta < 2.8$) that indicate a CB network reported for films containing nanoparticles prepared by drop-casting. This agreement suggests that the molecular network is found to operate as an electronic circuit [2,3].

As one function of a neural network, the molecular network with V_{th}. elements should exhibit SR, which improves the input signal by the superimposition of noise. Output signals were systematically measured by changing the amplitude of white noise against the small periodic square wave as input signal. No output signal is detected for the small input of periodic square wave with no noise. When the amplitude of white noise exceeds the threshold, the output signals synchronized to the input signal are clearly observed [3,4].

When no noise is added, the correlation coefficient (C.C.) between input voltage and output current is 0.3, which is possibly caused by the resemblance between the input reference and transient response spike signals in the output current. The C.C. values gradually increase with the noise amplitude and show plateau at around 0.9. The signal-to-noise ratio (SNR) which was obtained by fast Fourier transform (FFT) of the individual output signals shows clear peak with specific noise amplitude. These results indicate that SR phenomena occur in the molecular network suggesting first step toward next-generation architecture for future molecular neural network devices in molecular electronics.

References

[1] Y. Otsuka, Y. Naitoh, T. Matsumoto, W. Mizutani, H. Tabata, T. Kawai, "A Simple Fabrication Method of Nanogap Electrodes for Top-contacted Geometry: Application to Porphyrin," *Nanotechnology*, vol.15, pp. 1639-1644, 2004.

[2] Y. Hirano, Y. Segawa, F. Yamada, T. Kuroda-Sowa, T. Kawai, T. Matsumoto, " Mn_{12} molecular redox array exhibiting one-dimensional Coulomb blockade behavior," *J. Phys. Chem.* C, vol. 116, pp.9895–9899, 2012.

[3] Y. Hirano, Y. Segawa, T. Kawai, T. Matsumoto, "Stochastic Resonance in a Molecular Redox Circuit," *J. Phys. Chem.* C, vol.117, pp.140−145, 2013.

[4] Y. Hirano, Y. Segawa, T. Kuroda-Sowa, T. Kawai, T. Matsumoto, "Conductance with stochastic resonance in Mn_{12} redox network without tuning," *Appl. Phys. Lett.* vol.104, pp.233104-1-4, 2014.