Spatiotemporal Pattern Memory in

Network of Coupled Electrochemical Oscillators

Yasuyuki Miyakita†; Antonis Karantonis‡, Seiichiro Nakabayashi†;
†Saitama University, Saitama 338-8570, Japan,
‡National Technical University of Athens, Zografou 15780, Athens, Greece

[Introduction]

Synchronization behavior is ubiquitous phenomena in nervous systems, and synchronicity of coupled neurons is believed to be one of the possible ways for accomplishing sophisticated actions such as cognition as well as associative memory. A phenomenological resemblance between electrophysiological and electrochemical oscillators has been suggested in the past. Recently we reported that the dynamical behavior of coupled electrochemical oscillators has features similar to coupled neural cells [1].

In the present work, a network of coupled relaxation type electrochemical oscillators is investigated. It is shown that if the network is controlled potentiostatically with a point reference electrode, the action of connections between oscillators can be tuned to be either excitatory or inhibitory by changing the cell geometry [2]. Also we demonstrate that globally coupled inhibitory network of electrochemical oscillators have a potentially large capability to stored information in the form of spatially and temporally patterned pulse train. To perform it, we constructed an experimental framework at which number of electrochemical oscillators can be driven and monitored as well as perturbed selectively. It is demonstrated that permutation of pulse train can be selectively excited due to applying single laser illumination as an external perturbation.

[Method]

Our experimental tool is self-sustained current oscillations during Fe electrodissolution in 1M H_2SO_4 solution. Each electrode was made from pure Fe wires of 1 mm diameter. The electrodes were embedded in resin in a way such reaction takes place only at the ends of the Fe wire. The electrodes assembly was used as working electrode in a standard three-electrode arrangement with respect to SCE reference electrode with Haber-Luggin capillary. The working electrodes were connected to the potentiostat through individual resistors of 1 Ω in order to measure the currents of the electrodes independently. Under such condition, actions of connections between oscillators depend strongly on the cell geometrical parameters, d_{ij} and l, denote distance between each working electrode and distance between working assembly and reference electrodes, respectively. One of the electrode of the assembly was perturbed with a second harmonic light (λ = 532nm) from Nd:YAG laser. The use of laser will allow us perturb the network in systematic way. It allow us perturb desired cell of network at the specific timing.

[Result]

Here let us consider a set consisting of four cells arranged in a regular square with side d mm long. The four oscillators are coupled through electrolyte in nonlocal manners[3]. For large value of l where both of diagonal and adjacent oscillators communicate through excitatory manner, all four oscillators excite each other and thus synchronize in-phase for any initial conditions tested experimentally. For small l where all oscillators communicate through inhibitory manners, all of the four oscillators inhibit each other and oscillate out-of-phase and oscillatory current peaks never overlap as shown in Figure (a).

During out-of-phase synchronized state, sequence of pulse train is preserved and each oscillator is shifted by almost $1/N$, 0.25 for N=4, of period from neighbor within over the range of applied potential. Notice that the system has (N-1)! multiple stable steady states coexistent as permutations of current pulse train. It depends only on initial conditions or external perturbation.

Next let us investigate response of network for external perturbation by means of utilizing illumination of pulse laser beam. A representative example of response of network for single perturbation is shown in Figures (a)(b). It is obvious that the network synchronized with the sequence {4, 3, 2, 1} before the applying pulse perturbation, whereas when once external perturbation was applied network synchronized with sequence {4, 3, 1, 2}. Figure(b) shows the trajectory of phase relation represented by three phase coordinates during the course of whole time series of (a). The system usually stays some specific point in three dimensional map, however when external perturbation is applied to the network, the system jumps to another specific point as presented.

In the network a given set of spatiotemporal pattern replays as a stored symbol and is induced by external inputs. As a conclusion, the network of the coupled relaxation electrochemical oscillators functions as a memory.

[Reference]

[1] A.Karantonis, Y.Miyakita, S.Nakabayashi, *Phys. Rev. E* 65, 046213(2002).
[2] A.Karantonis, M.Pagitsas, Y.Miyakita, S.Nakabayashi, *J. Phys. Chem. B*, *107*, 14622-14630(2003).
[3] K. Krischer, *J. Electroanal. Chem.* 501, 1-21(2001).

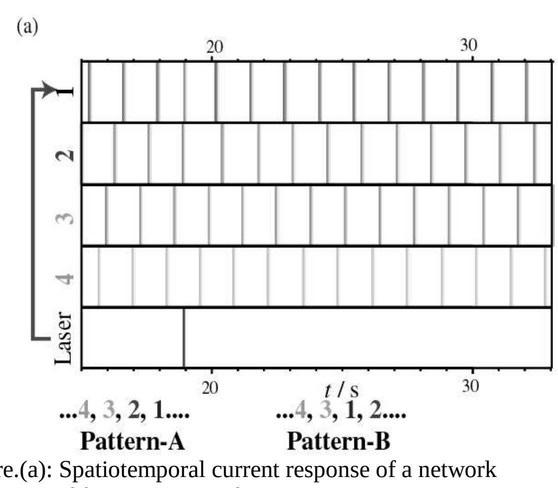
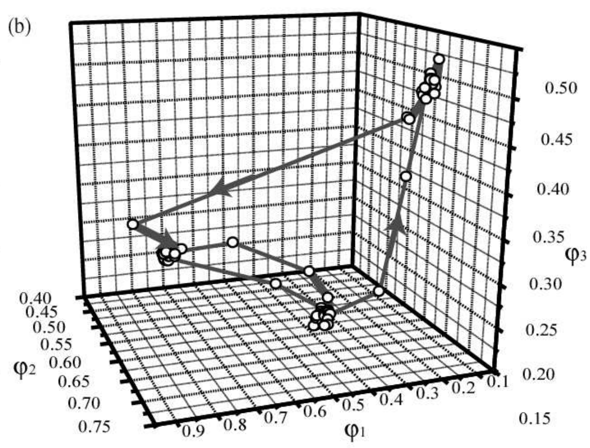


Figure.(a): Spatiotemporal current response of a network consisting of four oscillators for 262 mV and d=5 mm. Depth of gray lines indicate current responses of each oscillator.



(b): Trajectory of phase relation under multiple pulse of laser stimuli. Each state is represented by phase coordinates, φ_1, φ_2 and φ_3 and the momentum of the peak as φ_4=0.