Synchrony and precision of chaotic electrochemical oscillators: effects of temperature and coupling

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In a network of complex dynamical systems (e.g., oscillatory circuits in the brain), the identification of connection topology is a challenging task. Synchronization theories play a pivotal role in understanding the communication between rhythmic elements. We study the role of precision chaotic oscillations on dynamics of single and small networks of electrochemical oscillators in order to gain insight into the features of chemical reactivity of a corrosion process.

The effects of temperature on complexity features of a single chaotic electrochemical oscillator are investigated using the anodic electrodissolution of nickel in sulfuric acid. The precision of chaotic oscillation is characterized by phase diffusion coefficient (D). It is shown that reduced phase diffusion coefficient (D/frequency) exhibits Arrhenius type dependency on temperature with apparent activation energy of 108 kJ/mol. The reduced Lyapunov exponent of the attractor exhibits no considerable dependency on temperature. These results suggest that the precision of electrochemical oscillations deteriorates with temperature and the variation of phase diffusion coefficient does not necessarily correlate with that of Lyapunov exponent. Modeling studies qualitatively simulate the behavior observed in the experiments: the precision of oscillations in the chaotic Ni dissolution model can be tuned by changes of a time scale parameter of an essential variable, which is responsible for development of chaotic behavior.

For studies on effect of coupling on precision, three locally coupled phase coherent chaotic oscillators (A-B-C) are considered first in nickel electrodissolution. As the interaction strength is increased among the electrodes, an onset of synchronization is observed where the frequencies become identical. Transition to synchronization was found to be accompanied by enhanced phase fluctuations that deteriorate the precision of the oscillations. By partial synchrony analysis of the phases of the oscillators, the direct (between A-B and B-C) and the indirect (between A-C) coupling can be identified and thus the network topology can be deduced.

Coupling experiments were also carried out at high temperature (35 oC) with three non-phase-coherent oscillators. In this system traditional phase definition using Hilbert-transform fails. With phase obtained through derivative Hilbert transform approach it is shown that enhanced phase fluctuation close to synchronization transition can also be observed.