Biomorphic Analog Devices based on Reaction-Diffusion Systems

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I introduce reaction-diffusion (RD) silicon devices for developing basic components of biomorphic computing systems. RD systems are usually modeled in terms of cellular automata (Fig. 1) and are known to enable sensible computation when both data and results of the computation are encoded in concentration profiles of chemical species; the computation is implemented via spreading and interaction of either diffusive or phase waves [1]. Thin-layer chemical systems are thought, therefore, to be massively-parallel locally-connected computing devices, where micro-volume of the medium is analogous to an elementary processor. Several ideas for practical applications that use the properties of RD systems have also been proposed, e.g., ideas for chemical image processing [2, 3], optimal path planning [4], and binary logic processing [5]. These results suggest that natural systems that make actions primarily for themselves will help us to both understand RD systems and reconstruct them in artificial reaction media.

Practical applications of the RD systems are, however, reduced due to waves traveling at very low speeds which makes real-time computation senseless. To overcome the speed-limitations while preserving unique features of RD computers, work has been done on semiconductor RD computing devices:

1. **CMOS reaction-diffusion chips** [6]; I present the analog CMOS chips (Fig. 2) that implement a 2D array of excitatory analog circuits, including the Oregonators, Wilson-Cowan oscillators and Lotka-Volterra oscillators. Remarkably, the Oregonator chip exhibits various vital phenomena; i.e., production of traveling and spiral waves, as observed in natural reaction-diffusion systems (Fig. 3). Since these chips can operate at much faster speeds than natural systems, they could be possible candidates for practical reaction-diffusion computers.

2. **Excitable reaction-diffusion devices using minority-carrier transport in semiconductors** [7]; other research has been done on an idea to use the minority carriers in the semiconductors as diffusion substances. Chemical reactions are imitated by *reaction device* that regulate the concentration of minority-carriers (Fig. 4).

3. **Single-electron reaction-diffusion devices** [8]; the device consists of a 2D array of single-electron oscillators that are combined with each other though capacitive diffusion devices (Fig. 5a). The device produces animated spatiotemporal patterns of tunneling phenomena; e.g., rotating spiral patterns.

In this talk, I will present simulation or experimental results of RD devices we have developed, which may enable the development of applications based on natural RD phenomena using CMOS devices and nanostructures.

References

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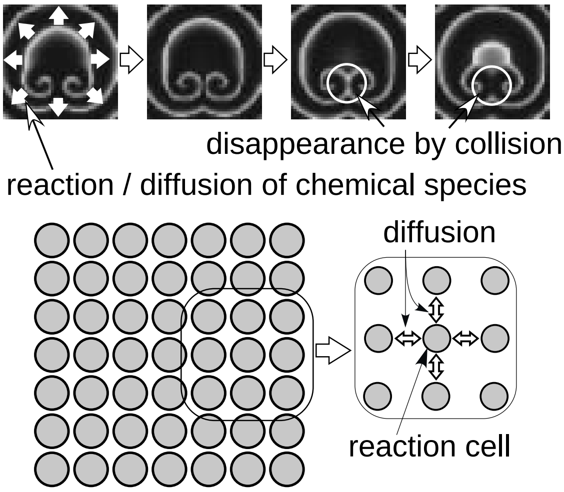

Fig. 1. Reaction-Diffusion (RD) model.

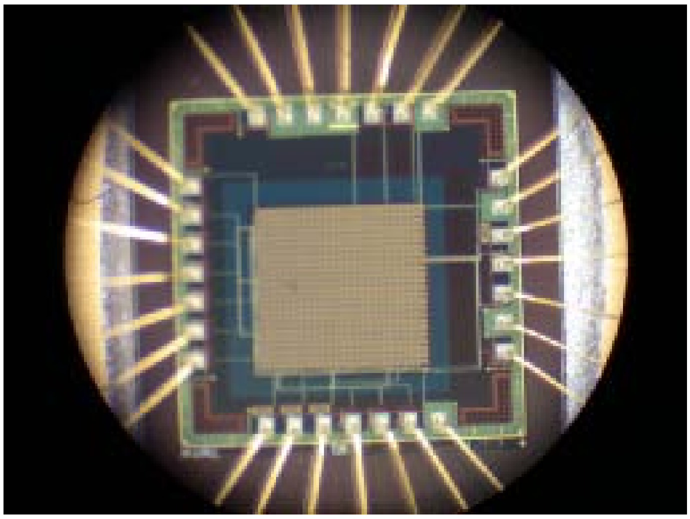

Fig. 2. Fabricated RD chip with 0.5-um CMOS.

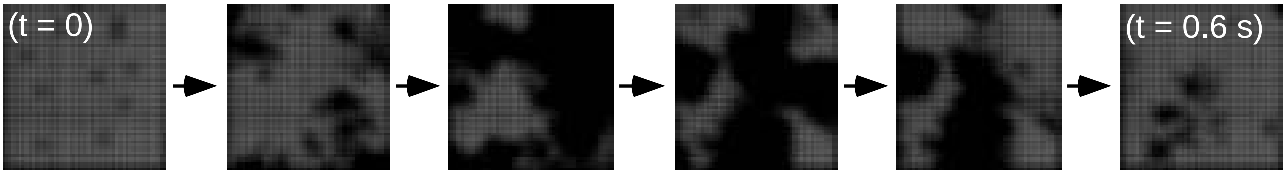

Fig. 3. Experimental results of fabricated RD chip with 24 x 24 Oregonator cells.

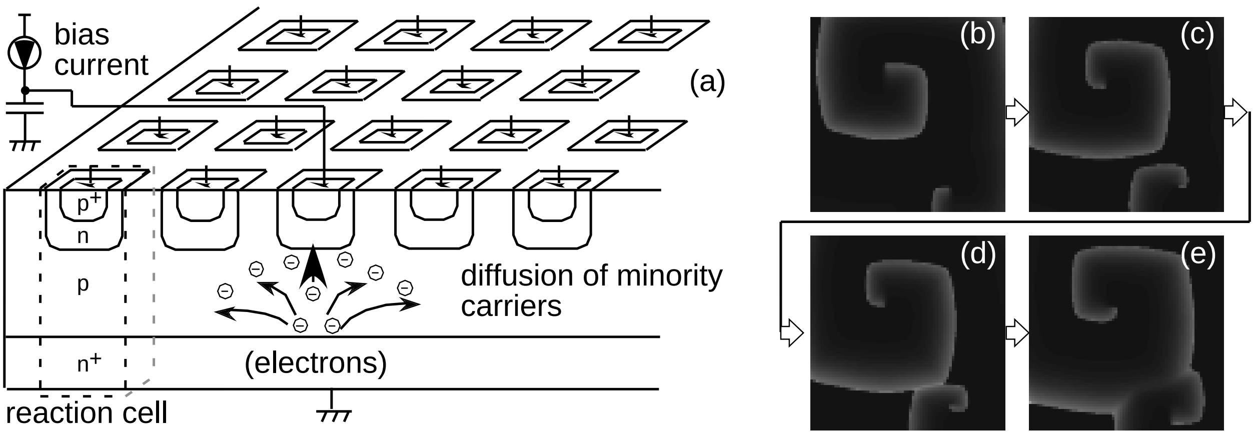

Fig. 4. RD device consisting of *pnpn* reaction cells (a) and its simulation results (b)-(e).

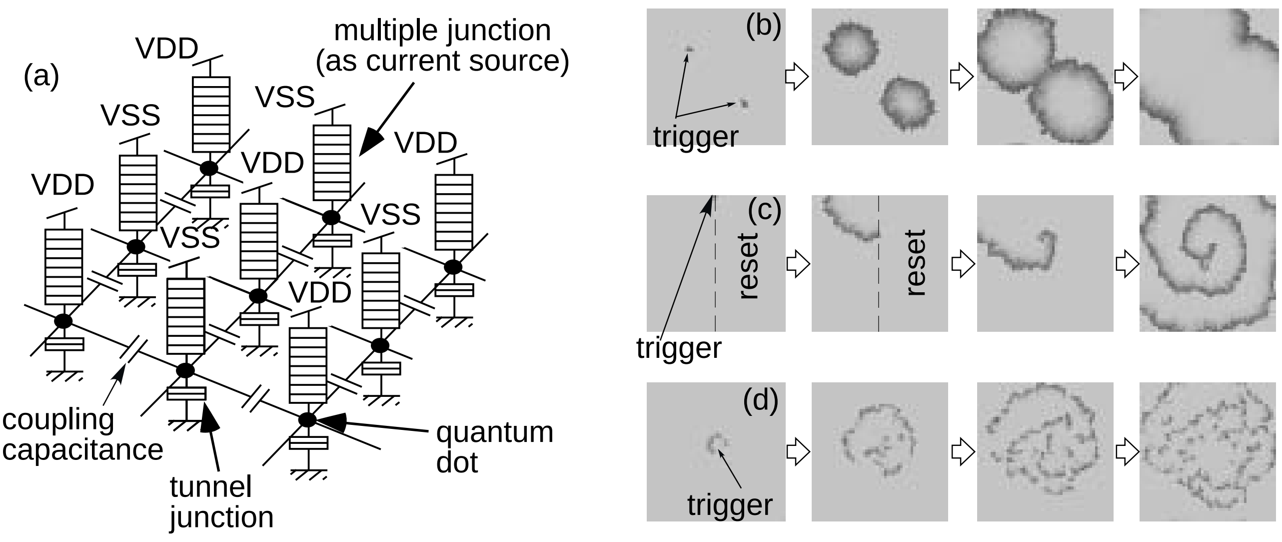

Fig. 5. Possible structure of quantum RD device (a) and its simulation results (b)-(d).