A single-electron device for an analog computation

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Introduction

Analog computation is a processing method that is used to solve mathematical problems by applying an analogy of a physical system to the problem. It is quite different from commonly used binary-digital computation methods, and can solve various complex problems in a short time. In this paper we propose an analog-computation device consisting of a single-electron nonlinear wave system. This device promises to solve maze problems quickly by using the properties of nonlinear waves.

Solving maze problems using the properties of nonlinear waves

Traveling nonlinear waves in a spatially distributed, excitable medium arise from the coupling of a positive feedback process with some form of transport, for example, autocatalytic chemical reaction with diffusion of chemicals. Such nonlinear wave travels at a fixed velocity without attenuation and vanishes on collision with walls, obstacles, and other waves, as shown in Fig. 1. We can use these properties to solve maze problems [1, 2]. Suppose a maze is set in an excitable medium, and a wave is excited at the entrance of the maze. The wave will then split at each divergent point during its propagation and therefore reach every corridor in the maze. When a split wave anticipates other waves in reaching a corridor, the anticipated waves vanish upon collision with the anticipating wave, as shown in Figs. 2 (a), (b), and (c). The result is a ripplet indicating the shortest distance from the entrance. Therefore we can find the optimal route, the solution to the maze problem, by tracing the flow of the wave to the entrance, as shown in Fig. 2 (d).

Single-electron circuit producing and transmitting nonlinear waves

The single-electron circuit is a nonlinear electrical circuit, capable of producing nonlinear voltage waves, which can be used for solving maze problems. Figure 3 shows the device we propose for solving maze problems. It consists of nonlinear oscillators to imitate the autocatalytic chemical reaction and diffusive-coupling elements to imitate the diffusion of chemicals. We used multiple-tunneling junction oscillators as the nonlinear oscillators, and coupled them using capacitors. The multiple-tunneling junction oscillators consist of a nanodot (a minute dot), a main tunneling junction C_j, and a multiple-tunneling junction C_m (a set of many tunneling junctions connected in series), as shown in Fig. 4 (a). The oscillators are set to the excitatory state by adjusting a bias voltage immediately below the tunneling threshold. Under these conditions, the oscillators produce a monostable oscillation excited by an external trigger, as shown in Fig. 4 (b). When the oscillators are placed in a two-dimensional structure with capacitive coupling, they will work together to operate as an excitable medium. The device is in a stable state as it stands. Once a triggering signal is applied to an oscillator in the device, excitation of electron tunneling will start in the oscillator, and an excitation wave of nanodot voltages will propagate in all directions to form an expanding circular pattern, as shown in Fig. 5.

Implementing a maze problem on the single-electron circuit

Using this device, we made an analog of a given maze as follows. To imitate the walls in the maze, we reduced the bias voltage for the corresponding oscillators so that no tunneling could occur even if we applied a trigger. Other oscillators corresponding to the corridors were set to the excitatory state. We confirmed the operation of the device by computer simulation. We generated a wave at the entrance and observed the wave proceeding through the maze. Figure 6 shows the wave moving forward, penetrating every position in the maze, and finally reaching the exit. By tracing the flow of the wave that reached the exit, we were able to solve the maze problem.

References

[1] O. Steinbock, Á. Tóth, and K. Showalter, *Science*, **267**, 868, 1995.
[2] M. Hiratsuka, T. Aoki, and T. Higuchi, *IEEE Trans. Circuit and Systems-I*, **46**, 294, 1999.

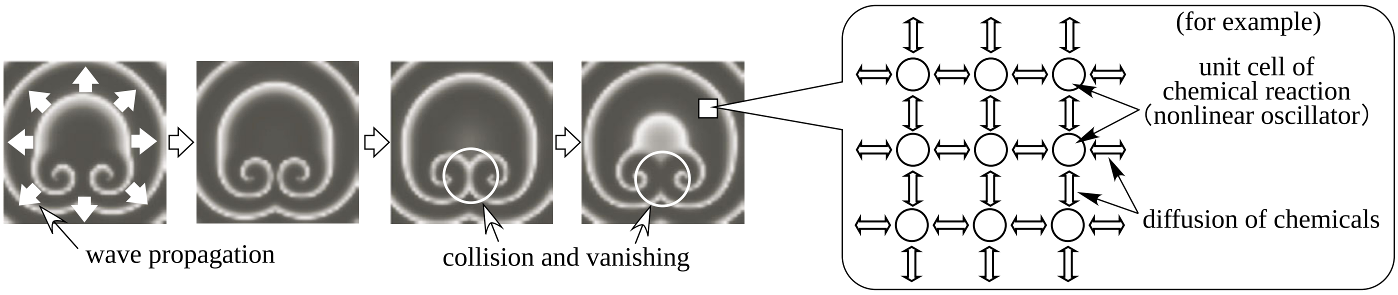

Fig. 1 Properties of a nonlinear wave−−the wave travels at a fixed velocity and vanishes on collision with other waves

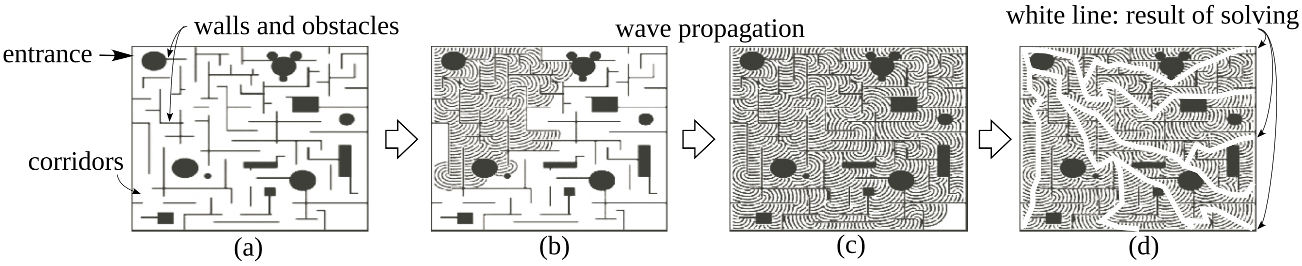

Fig. 2 Solving maze problems using wave characteristics. The wave splits at each divergent point during its propagation and reaches every corridor in the maze. We can find the optimal route, the solution to the maze problem, by tracing the flow of the wave from the exit to the entrance (M. Hiratsuka et al., 2002).

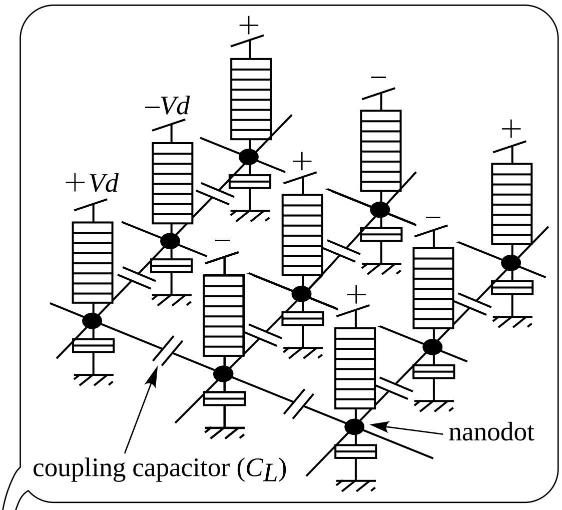

Fig. 3 Construction of a single-electron nonlinear wave system.

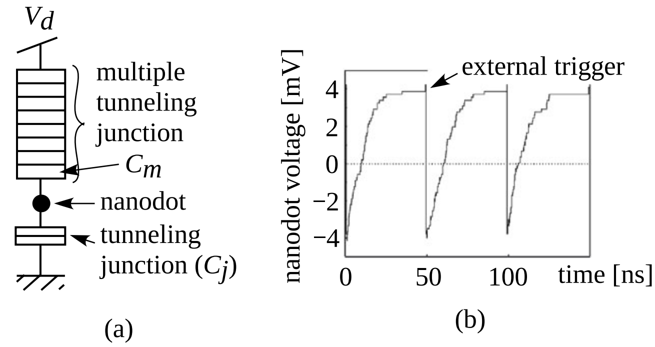

Fig. 4 Single-electron nonlinear oscillator: (a) the circuit configuration, (b) excitatory operation.
(Parameters: C_j = 10 aF, N (number of C_m) = 50, C_m = 500 aF, and V_d = 7.8 mV for excitatory operation.)

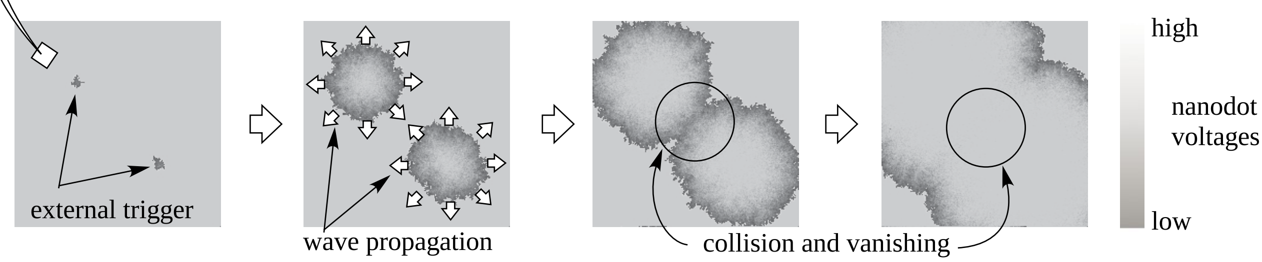

Fig. 5 Nonlinear voltage waves produced by the single-electron nonlinear wave system. The phenomenon has the properties of nonlinear waves that are propagating, colliding with other waves and vanishing.

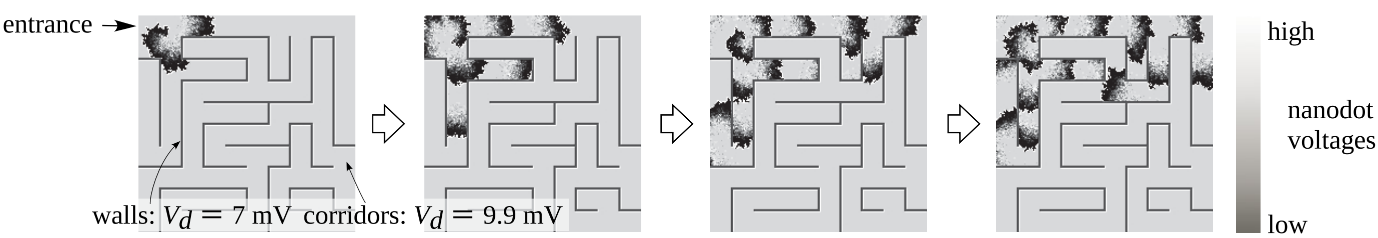

Fig. 6 Propagating wave in a maze on the single-electron nonlinear wave system. The voltage wave propagates along the corridors from the entrance. Because the low bias oscillators operate as walls, no electron tunneling occurs at the oscillators. (Parameters: C_j = 10 aF, N (number of C_m) = 50, C_m = 500 aF, and C_L = 2 aF.)