Growth Oscillation in Chemical Garden

([1]*Hiroshima University*, [2] *University of Tokyo*) ○Yujin Kubodera,[1] Muneyuki Matsuo,[1,2] Satoshi Nakata[1]

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A chemical garden is a precipitation tube growing from metal salts soaked in an aqueous Na_2SiO_3 solution. The formation of tubes is also seen in living organisms, such as the growth of plants and the formation of blood vessels. While general chemical gardens grow upward from the bottom of a cell, plants, and blood vessels grow fluidly regardless of their vertical or horizontal orientation. Recently, chemical gardens that grow fluidly in various directions on a horizontal plane have been reported.[1] The above attracted attention as a model experimental system for living organisms' autonomous and complex tube formation. However, the growth was limited because it occurred only on a flat surface and required external laser guidance.

In this study, an aqueous $CuCl_2$ solution was injected *via* a needle (inner diameter: 0.3 mm) from the bottom of a tank (1 mm thick, 64 mm wide, and 42 mm high), filled with an aqueous Na_2SiO_3 solution or a mixture of aqueous Na_2SiO_3 and NaCl solution. Here, I correspond to the injection rate of the aqueous $CuCl_2$ solution. First, the direction of tube growth was observed at $[CuCl_2]$ = 1.3 M and I = 0.25 or 20 μL min^{-1}. As a result, at I = 0.25 μL min^{-1}, the tube grew vertically upward (Figure 1a-i). On the other hand, at I = 20 μL min^{-1}, the tube grew laterally (Figure 1a-ii). Figure 1b shows the phase diagram of $[CuCl_2]$ and I in the growth direction. The threshold values of I between upward and lateral growth decreased with increasing $[CuCl_2]$. Next, the tank was filled with a mixture of aqueous 0.6 M Na_2SiO_3 and 1.0 M NaCl solution. As a result, oscillations in the direction of tube growth were observed at I = 10 μL min^{-1}(Figure. 1c). The tube growth direction is thought to be determined by the density and osmotic pressure difference between the aqueous $CuCl_2$ solution inside the tube and that of the outer aqueous Na_2SiO_3 solution. The mechanism of the oscillations will be presented by clarifying the dependence of the period and amplitude of the oscillations on [NaCl] and I.

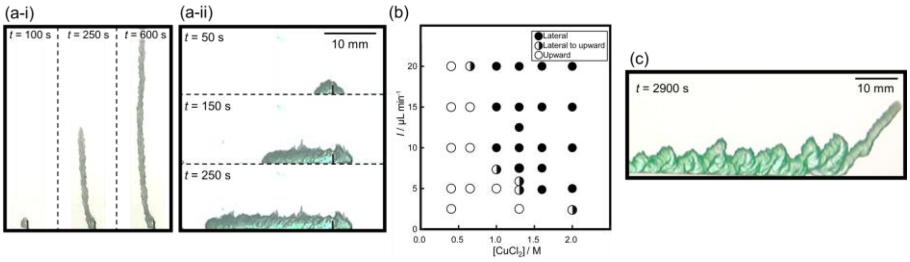

Figure 1. (a) Time-variation of snapshots on tube growth observed at I = (a-i) 2.5 and (a-ii) 20 μL min^{-1} in $[CuCl_2]$ = 1.3 M (side view). (b) Phase diagram of upward (empty circles), upward growth *via* lateral one (half-filled circles), and lateral (filled circles) growth depending on $[CuCl_2]$ and I. (c) Snapshot on tube growth observed at I = 10μL min^{-1} with 0.6 M Na_2SiO_3 and 1.0 M NaCl.

1) G. J. T. Cooper et al., *J. Am. Chem. Soc.* **2011**, 133, 15, 5947–5954.