Supporting Information

Controlling the Collective Behaviors of Ultrasound-Driven Nanomotors by Frequency Regulation

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**FEM Simulation**

The acoustic equation (Helmholtz equation), as described by Louisnard [1], which ignores thermal and viscous losses due to cavitation, is expressed as follows:

|  |  |
| --- | --- |
|  | (1) |

here, represents the acoustic pressure, is the density of the liquid, and k is the wave number. In solid boundaries, the solid mechanics equation describes how an object deforms and moves under the influence of forces. Specifically, the linear elasticity equation is expressed as:

|  |  |
| --- | --- |
|  | (2) |

*u* represents the displacement field, describing the displacement of points within the object, is the density of the solid,is the stress tensor, indicating the internal forces at different points within the object. And acoustic-solid-liquid coupling term:

|  |  |
| --- | --- |
|  | (3) |

This term represents the interaction between the acoustic field and the solid object, where *n* is the outward normal vector. The two-dimensional distribution maps of the acoustic pressure field are obtained by applying the finite element method to solve the aforementioned equations.

**Characterization**

Scanning electron microscope (JSM-7500F SEM.) and transmission electron microscope (JEOL F200 TEM) with energy dispersive spectroscopy system were employed to characterize the morphology and structure information of nanomotors. the near-infrared absorption (NIR) spectrum was recorded using a UV-3600 iPlus UV visible near-infrared spectrophotometer. X-ray photoelectron spectroscopy (XPS) was analyzed by an AXIS Supra X-ray photoelectron spectroscopy. The X-ray diffraction (XRD) patterns of the samples were recorded using a SmartLab (9k) X-ray diffractometer.

**Supporting Videos**

**Video S1. Three distinct collective behaviors of nanomotors in ultrasonic field with different frequencies.** Part 1, Vortex-shaped rotation (1.3MHz); Part 2, Stripe-like chains (1.4 MHz); Part 3, Assembly into clusters and disassembling (2.8MHz).

Video S2. The transformation of collective behavior between different patterns.

Video S3. Changing the direction of stripe-like patterns from the *x*-axis direction to the *y*-axis direction.

**Supporting Figures**

A black and white image of a light in the dark

Description automatically generated

**Figure S1.** Lattice diffraction patterns captured by high-resolution transmission electron microscopy.

**References**

1. Louisnard, P. A simple model of ultrasound propagation in a cavitating liquid. Part I: Theory, nonlinear attenuation and traveling wave generation. *Ultrason. Sonochem.* **2012**, *9 (1)*, 66-76.