Remotely powered floating microswimmers as colloidal microparticle manipulators

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Abstract Text

Remote propulsion of micro scale mobile agents has great potential as wireless manipulation tools for smaller scale objects. These untethered micro mobile agents can enlarge the area of manipulation that can open broad applications. Especially in harsh and inaccessible environments like toxic liquids, these untethered devices are important because they enable some applications which were impossible before. Liquid environment manipulation using untethered mobile agents can be used as new manipulation methods in biologic and in interest of such novel manipulation tools. However low Reynolds number physics severely limits the propulsion performances of such small scale mobile agents. To overcome such physical limitation, biologically inspired artificial flagella [1] have been demonstrated to swim efficiently in liquid environments with magnetic fields. The swimming performance of electro-osmotic propulsion could be also even more efficient [2]. However most of such micro scale mobile agents liquid applications are limited to the immersed environment. If macro scale, the floating diode propulsions were demonstrated by electro-osmotic force [3]. However floating micro scale mobile agents were not much studied in their propulsions and manipulation. In this paper, the propulsion of floating microswimmers is proposed to demonstrate the cargo transport of colloidal micro particles. Since these floating mobile microswimmers can trap and release the massive amounts of colloidal particles in parallel, they can be applied to long distance wireless liquid manipulation tools.

Floating microswimmers consist of ferromagnetic nickel layer (24 µm thickness) that is deposited onto a PMN-PT piezoelectric layer (200 µm thickness) (Figure 1.a). The bottom layer (PMN-PT) is in contact with the water/air interface. Figure 1.a shows the layer profiles. While this PMN-PT layer is used to create local electro-osmotic flow driven by the charges induced during the rotation, the nickel layer is to achieve the interaction with the external magnetic field. The principle of wireless colloidal micromanipulators is described in the figure 1. Three-dimensional Helmholtz coils are used to generate the external rotating field. When the external rotating magnetic field is generated, the microswimmer rotates at the same frequency as the rotating field. During rotation, the microswimmer bottom surface can be charged in negatively or positively depending on the material. Positively charged, the surrounding area in a centric circle is negatively charged. When the rotation occurs, the given circular crown experiences the potential in alternating way like in the figure 1.b. This can induce the dielectrophoretic force with charged particles (glass microbeads, diameter around 3-5 µm) that applies force toward the center of rotation. At the same time, the hydrodynamic friction between the water and the bottom surface of the microswimmer creates an outward translational force from the center of rotation which controls the trapping can be tuned by rotating frequency. When these two anti-directional forces are counter balanced in a certain range of frequency, the group particles rotation is generated. The particle trapping by the rotating microswimmer is demonstrated in the figure 2.a. By increasing the frequency, the trapping performance is simply measured by the diameter of the mass particles crown. Figure 2.b and 2.c shows the curve of trapped area versus the given frequency in two types of interfacing surface which are PMN-PT and Nickel respectively.

Figure 3 shows the successful demonstration of particle trap and dislocation controlled by rotational frequency following the strategy shown in Figure 1c. The gradient magnetic field is added to dislocate the microswimmer from the trapped micro particles. The trajectories of the micro particles and the microswimmer are displayed in Figure 4. These results show that the wirelessly controlled floating microswimmers can be used as non-contact colloidal manipulators which are promising to wireless cargo transporters of molecules or biological samples in liquid environment.

References

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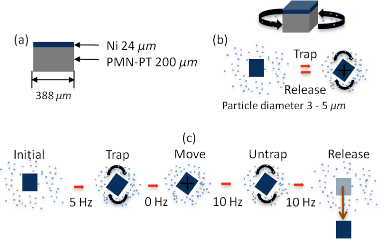

Figure 1. (a) Schematic of a microswimmer structure, (b) The colloidal trap and release, (c) The strategy of frequency-controlled trap and release.

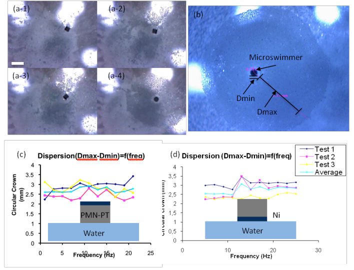

Figure 2. (a) Trapping procedure by microswimmer, (b) Trapped micro particles by floating microswimmer, (b) Area of trapped colloids in frequency domain: (c) PMN-PT–water interface, (d) Nickel-water interface.

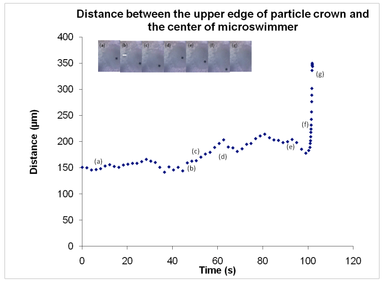

Figure 3. Distance between microswimmer and particles during trap and release manipulation: (a) Applying rotating magnetic field at 5Hz, (b-d) No rotation but gradient pulling of microswimmer to move the particles. e) Applying magnetic field at 10Hz, f-h) Gradient pulling of microswimmer and release of particles (scale bar 1mm).

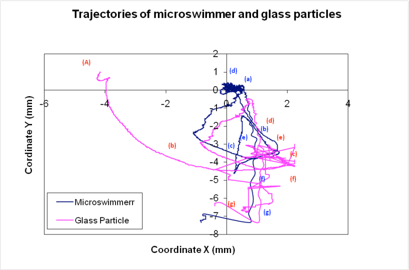

Figure 4. Trajectories of the microswimmer and of the micro particles mass during trap and release manipulation.