Supporting Information

**Disk-Like Nanojets with Steerable Trajectory Using Platinum Nozzle Nanoengines**

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**ESI Videos:**

**ESI Video 1** Circular motion of the nanojet with one off-center Pt nozzle nanoengine.

**ESI Video 2** Linear motion of the nanojet with two identically and symmetrically distributed Pt nozzle nanoengines.

**Equipment:**

1. Advanced Vacuum/vision 310 MK II: gas 1 5% SiH$_4$/N$_2$ and flow rate 160 sccm, gas 2 N$_2$O and flow rate 1420 sccm, gas 3 N$_2$ and flow rate 240 sccm, pressure 800 mTorr, temperature 300°C;
2. Fumehood for KOH etching: temperature 120°C;
3. Karl Suss Deltta VPO Primer: temperature 100°C;
4. Cee Spin Coater: speed 5000 rpm, spin duration 30 s;
5. Karl Suss MA56 mask aligner: expose type vacuum, expose time 5 s, power 275W;
6. Fumehood for photoresist development: room temperature;
7. Semitool/PSC-101 drying machine: speed 1600 rpm, spin duration 2 min;
8. Hot Plate/MODEL HP50: temperature 100°C;
9. Hyper HAD color video camera;
10. Mitatoyo WF microscope: magnification 10;
11. HITACHI S-3500N scanning electron microscope: voltage 5 kV;
12. Magnetron sputter system: gas Ar and flow rate 20 sccm, base vacuum 3 mTorr, power 200W;
13. E-beam evaporator/EDWARDS FL 400: gas N$_2$, current 25 mA, voltage 4.96 kV, temperature RF, pressure 3.2 mTorr;
14. JEOL JSM-5600LV field emission scanning electron microscope: voltage 20 kV.

**Materials:**

1. Sulfuric acid (purchased from Tee Hai Chem Pte Ltd, Singapore);
2. HMDS (purchased from Clariant Pte Ltd, Singapore);
3. Photoresist 7220 (purchased from AZ Electronic Materials, Singapore);
4. AZ 300MIF developer (purchased from AZ Electronic Materials, Singapore);
5. N$_2$ gas (purchased from Soxal, Singapore);
6. Gold (purchased from Analytic Technologies Pte Ltd, Singapore);
7. Nickel (purchased from MOS Group, Singapore);
8. Platinum (purchased from MOS Group, Singapore);
9. Acetone (purchased from Avantor Performance Materials, USA);
10. Iso-propyl alcohol (purchased from Avantor Performance Materials, USA);
11. Potassium hydroxide (purchased from Aik Moh Paints & Chemicals Pte Ltd, Singapore);

**Software**

1. SEMICAPS 2200C_3 imaging system;
2. Osprey swiftcap video capturing;
3. INCA software;
4. ImageJ.

**Derivation of the driving force** \( F_{\text{drive}} \) **stemmed from the momentum change**

Generally, \( \text{H}_2\text{O}_2 \) can decompose into \( \text{H}_2\text{O} \) and \( \text{O}_2 \) molecules by the catalysis of Pt.\(^1,2\) During the \( \text{H}_2\text{O}_2 \) decomposition, \( \text{O}_2 \) bubbles are generated and detached from the surface of the Pt nozzle nanomotors of the Au-Ni-Pt nanojets. SI Figure S-1 demonstrates two states of an integrated Au-Ni-Pt nanojet-oxygen bubble system. In the beginning, \( \text{O}_2 \) bubbles are attached to the surface of the Au-Ni-Pt nanojets, called the growing state, in which the nanojets and \( \text{O}_2 \) bubbles have the joint velocity of \( v_1 \). After a period of time of \( \Delta t \), \( \text{O}_2 \) bubbles are detached from the Pt-surface, called the detaching state. At this state, the Au-Ni-Pt nanojets have a velocity of \( v_2 \), while the \( \text{O}_2 \) bubbles have a distinct velocity, named \( v_0 \). According to the Momentum Conservation Law, one can obtain the following equation

\[
(m + \Delta m)v_1 = mv_2 - \Delta mv_0 \tag{SI-1}
\]

\[
m(v_2 - v_1) = \Delta m(v_1 + v_0) \tag{SI-2}
\]

where, \( m \) is the mass of one single Au-Ni-Pt nanojet, \( \Delta m \) represents the mass of each individual detached \( \text{O}_2 \) bubble.

According to the Momentum Theorem, the driving force \( F_{\text{drive}} \) induced by one single detached \( \text{O}_2 \) bubble can be expressed as

\[
F_{\text{drive}} = \frac{m}{\Delta t} \frac{v_2 - v_1}{\Delta t} = \frac{\Delta m}{\Delta t} \frac{v_1 + v_0}{\Delta t} = \frac{\Delta m}{\Delta t} v_0 \tag{SI-3}
\]

After a period of time of \( \Delta t \), \( N \) \( \text{O}_2 \) bubbles are detached from the Pt-surface of the Au-Ni-Pt nanojets. Thus, the total driving force \( F_{\text{drive}} \) can be described as
At steady state, the Au-Ni-Pt nanojets reach a constant velocity of \( v \), namely \( v_1 = v_2 = v \). Thus, one can obtain

\[
F_{\text{drive}} = N F'_{\text{drive}} = \frac{\Delta m}{\Delta t} (v_1 + v_0)
\]

(SI-4)

SI Figure S-1. Schematic diagram for illustrating the generation of the driving force \( F_{\text{drive}} \) induced by the detachment of the \( \text{O}_2 \) bubbles.
Experimental set-up

SI Figure S-2. Microscopy set-up for characterizing and recording the disk-like Au-Ni-Pt nanojet’s steerable propulsion in aqueous H$_2$O$_2$ solution. The set-up was mainly composed of a microscope, sample, camera and computer.

The experimental set-up, as shown in SI Figure S-2, was established for investigating the nanojet’s motion. The set-up was mainly composed of four parts, which were an optical microscope, sample, camera and computer.

**Brownian motion speed of the Au-Ni-Pt nanojets**

In micro and nano regime, the linear diffused distance $x$ of an object can be described as in one dimensional space

$$<x^2> = 2Dt_{\text{diff}}$$  (SI-6)

where, $x$, $D$ and $t_{\text{diff}}$ are the diffusion distance, diffusivity and diffusion time of the object, respectively. By differentiating equation (SI-6), one can obtain that the Brownian motion speed $v_B$ is described as

$$v_B = \frac{D}{\sqrt{2Dt_{\text{diff}}}}$$  (SI-7)

Moreover, Einstein and Smoluchowski showed that the diffusivity $D$ of the object moving in a specific fluid is related to the coefficient of the friction $f$, and the diffusivity can be expressed as

$$D = \frac{f}{6\pi \eta a}$$
\[ D = \frac{K_b T}{f} \]  
(\text{SI-8})

where, \( k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/(s·K)} \) is the Boltzmann constant and \( T \) is the absolute temperature. The coefficient of the friction can be expressed as

\[ f = 6\pi \mu a \]  
(\text{SI-9})

where, \( \mu = 0.001 \text{ kg/(m·s)} \) is the dynamic viscosity of the media (DI water) and \( a \) is the effective length of the object. If \( t_{\text{diff}} = 1 \text{ s} \) and \( T=300 \text{ K} \), the Brownian motion speed of the fabricated Au-Ni-Pt nanojets is as follows

\[ v_B \approx 0.096 \text{ µm/s} \]  
(\text{SI-10})

**References**