<u>**Supplementary Materials**</u>

Fabrication of tungsten tip probes within three seconds by using flame etching

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(1) Flame etching processes of nine W wires (No. 1-9).

The total flame etching time of 0.5 s, 1.0 s, 1.5 s, 2.0 s, 2.5 s, 3.0 s, 3.5 s, 4.5 s, 5.5 s, 7.0 s, and 9.0 s. Total 99 SEM images.

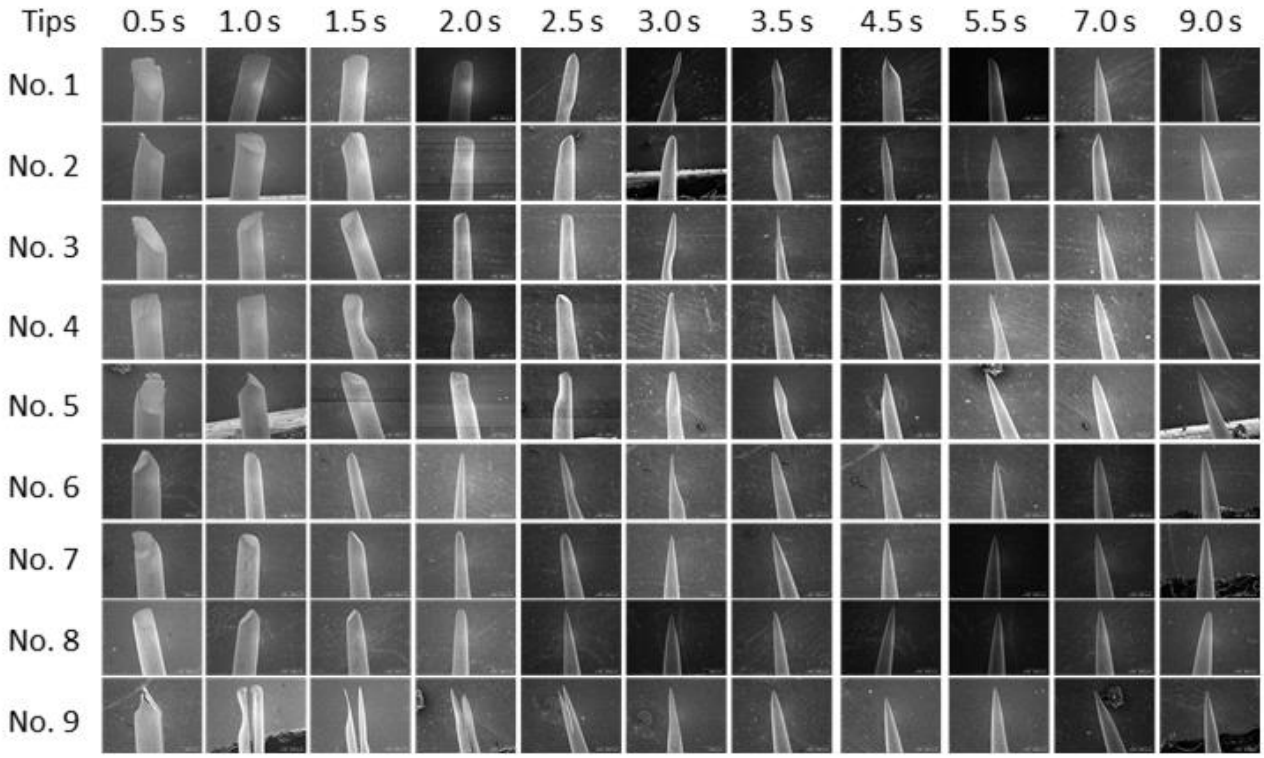

Figure S1. SEM images obtained from nine flame-etched W wires (tip No. 1-9) as a function of the total flame etching time.

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(2) Flame etching for the W wire at *L* = 35 mm and 50 mm.

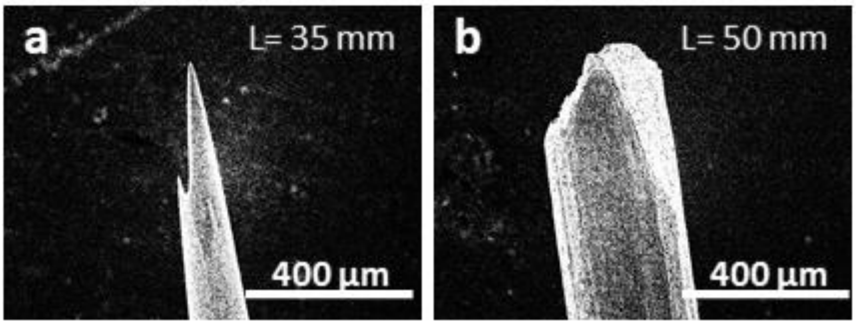

Figure S2. SEM images of W wires etched by lower flame temperatures for 10 s. W wires were etched at (a) L = 35 mm and (b) L = 50 mm by the LP+O_2 flame.

(3) Flame etching for PtIr, Ni, and Ta wires.

We have so far succeeded the flame etching only for W. Based on analysis in Fig. 4, generation and vaporization of WO_3 could be an important process to fabricate the tip. For further understanding of the flame etching mechanism, we tested other materials. If we use materials with melting temperatures much lower than W (3695 K), they will melt instead of being etched.

Figure S3a shows a PtIr wire case, which was heated by the LP+O_2 flame (~2300 K) at L = 5 mm using the setup in Fig. 1. For a PtIr wire, the cutting edge weakly flashed compared to the W wires, and finally formed a sphere ball at the apex. The result indicates that the tip apex melted inside the flame, which is consistent with the fact that the melting point of bulk PtIr alloy (~2100 K) is close to the flame temperature. This result suggests that the flame etching requires high vaporization rate before it starts to melt. We tested another material with a melting temperature much lower than the flame temperature. Nickel has a melting temperature of ~1720 K with a vapor pressure of 0.01-0.1 Torr at 1800-1970 K. Figure S3b shows the result of the Ni wire after flame etching for 3 s. The flashing was accompanied by sparks like a sparkler. Again, the apex has a sphere ball shape, indicating the apex melt inside the flame. However, compared to the PtIr case in Fig. S3a, the top of the ball was dented, which might be an indication that the vaporization occurred simultaneously inside the flame. Thus, materials having lower melting temperatures are not suitable for producing a tip shape.

Finally, the Ta wire with a melting temperature of 3290 K (very low vapor pressure: 10^{-8} Torr at 2230 K), similar to the W melting temperature of 3695 K, was tested. The Ta wire was set into the flame for 1.5 s. Figure S3c showed the result. A different apex: neither in a sphere nor in a tip, but forms a complicated spiral clunk form. The cut edge strongly flashed similar to the W wire. There might be reaction of Ta-oxide formation/vaporization on the surface. Although, so far, we do not find proper conditions, precise controls of the flame temperature and the etching time could produce a Ta tip in near future.

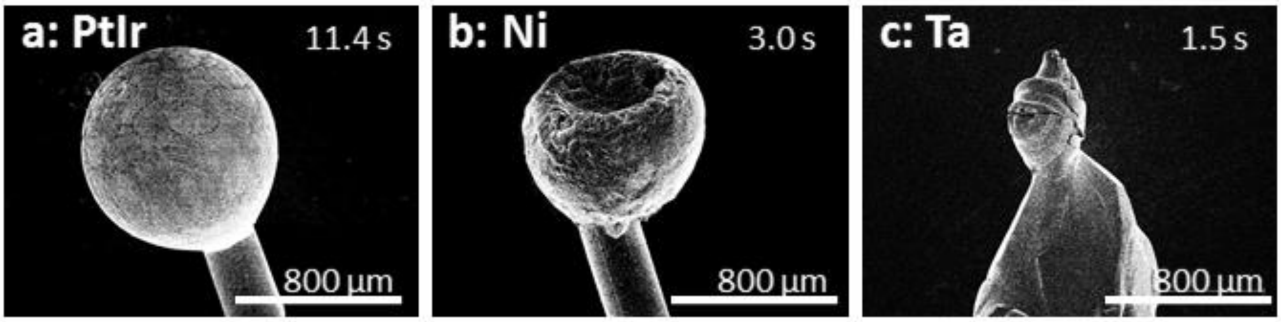

Figure S3. Flame etchings of (a) PtIr, (b) Ni, and (c) Ta, at L = 5 mm using the LP+O_2 gas flame. All metal wires have a diameter of 0.3 mm. The Total flame etching time is (a) 11.4 s, (b) 3 s, and (c) 1.5 s.

(4) STM in air using the flame-etched W tip.

A commercial JEOL-4200 air-STM setup was used.

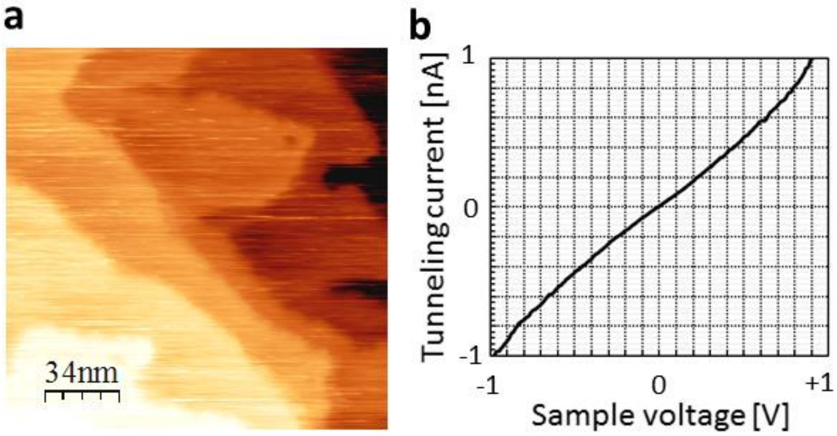

Figure S4. STM measurements were performed in air on a Au surface. (a) STM topographic image (170×170 nm^2, V_s = 1 V, I = 500 pA) and (b) $I(V)$ curve.

(5) Supplementary video during the W tip flame etching

http://adv.chiba-u.jp/nano/yamada-upload/20171130_flameetching.mp4