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Noble-Metal Covered W(111) Single-Atom Electron Sources

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Spatial coherence and brightness of electron sources are two key factors for their application to electron interferometry and holography, electron diffraction, and electron microscopies. It has been long considered that a smaller source size would yield a higher brightness and a larger spatial coherence width. Several methods for producing single-atom tips (SATs) or nanotips were developed by different groups. However, those SATs or nanotips have never been put into practical applications because they suffer from short lifetimes and their preparation methods are tedious and very unreliable.

A few years ago, Fu et al. demonstrated that a Pd-covered W (111) SAT could be created through vacuum deposition of one to two monolayer of a Pd film on a clean W tip surface followed by thermal annealing [1]. This tip is basically a nano-pyramid (Fig. 1) grown on top of a larger hemispherical tip. The major advantage of this method is that the growth of a faceted pyramidal tip is a thermodynamic process. Even if the tip is destroyed or contaminated, it can be regenerated through a simple annealing, which ensures its long operation lifetime. This type of SATs is also chemically stable. Even if a tip is exposed to the ambient condition, a SAT can be restored easily after annealing in vacuum. Later, this method was modified by Kuo et al. with both the preparation of a clean W tip surface and the deposition of a noble metal film in an electrochemical cell [2]. Pd-, Pt-, Ir-, Rh, and Au-covered W(111) SATs were successfully produced after the noble-metal plated tips were annealed in vacuum [2,3]. These pyramidal tips had the same structure as that of the Pd-covered W (111) SAT prepared by Fu et al., and could be regenerated at least several tens of times after destruction by repeated field evaporations. Also, these tips have a well-defined atomic stacking each time they are prepared. Amazingly, the noble-metal plated tips can be stored in the ambient condition for more than two years before annealing in vacuum. This greatly simplifies the application of these SATs, because annealing is a standard procedure in most instruments that uses a field emission tip.

We have characterized the properties of this type of single-atom electron sources. The electron beams have very small opening angles (2 to 3 degree, as seen in Fig. 2) and the brightness is one to four orders of magnitude higher than that of the state-of-the-art electron sources in electron microscopes [4]. We have recently demonstrated full spatial coherence for electron beams field emitted from this type of SATs using an electron point projection microscope [5]. The interference fringes of a single-walled carbon nanotube bundle exhibit a very high contrast and the fringe pattern extends throughout the entire beam width (Fig. 3), indicating good phase correlation at all points transverse to the propagation direction. Application of these sources can significantly improve the performance and expand the capabilities of current electron-beam based techniques. New instrumentations based on the high spatial coherence may make possible many advanced experiments.

[Reference]

[1] T. Y. Fu, L. C. Cheng, C. H. Nien, and T. T. Tsong, *Phys. Rev. B* **64,** 113401 (2001).
[2] H.-S. Kuo, I.-S. Hwang, T.-Y. Fu, J.-Y. Wu, C.-C. Chang, and T.T. Tsong, *NANO Lett.* **4(12),** 2379 (2004).
[3] H.-S. Kuo, I.-S. Hwang, T.-Y. Fu, Y.-C. Lin, C.-C. Chang, and T. T. Tsong, *Jap. J. Appl. Phys.* **45,** 8972 (2006).
[4] T. Ishikawa, T. Urata, B. Cho, E. Rokuta, C. Oshima, Y. Terui, H. Saito, A. Yonezawa, and T. T. Tsong, *Appl. Phys. Lett.* **90,** 143120 (2007).
[5] C.-C. Chang, H.-S. Kuo, I.-S. Hwang, and T. T. Tsong, *Nanotechnology* **20**, 115401 (2009).

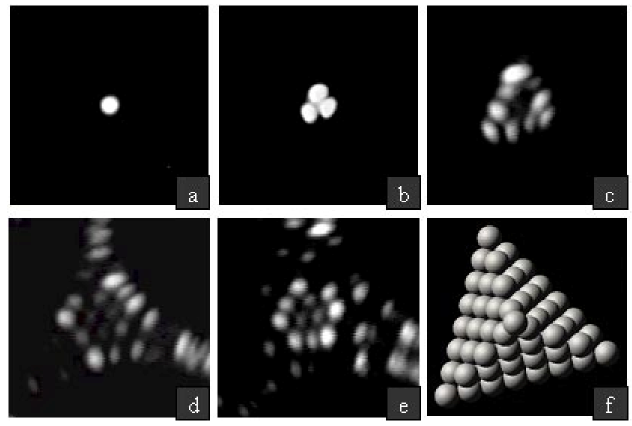

Fig. 1 (a)~(e) FIM images showing the structure of a Pd-covered W(111) SAT: (a) the top layer consists of only one atom; (b) the second layer three atoms; (c) the third layer 10 atoms; (d) the fourth layer 15 atoms; (e) the pyramidal structure is destroyed by the continuous field evaporation; (f) a 3-D hardball model of the nano-pyramid.

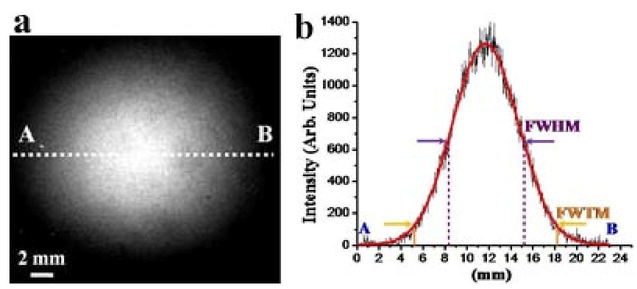

Fig. 2 (a) Field emission pattern of a Ir-covered W(111) SAT at a voltage of -1400 V. The scale bar at the lower left-hand corner indicates a length of 2 mm on the screen, corresponding to an angle of 0.67°. (b) Intensity profile along the dotted line AB in (a) with fitting of a Gaussian distribution (the thick red curve). The full width half maximum (FWHM) of the beam is measured to be ~ 7 mm, corresponding to an opening angle (2θ) of only 2.4°.

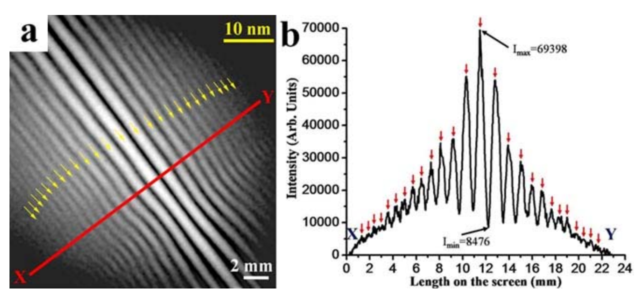

Fig. 3 (a) Interference pattern of a carbon nanotube bundle taken with a single-atom electron source at the tip bias of -89 V. (b) Intensity profile along the line XY in (a).