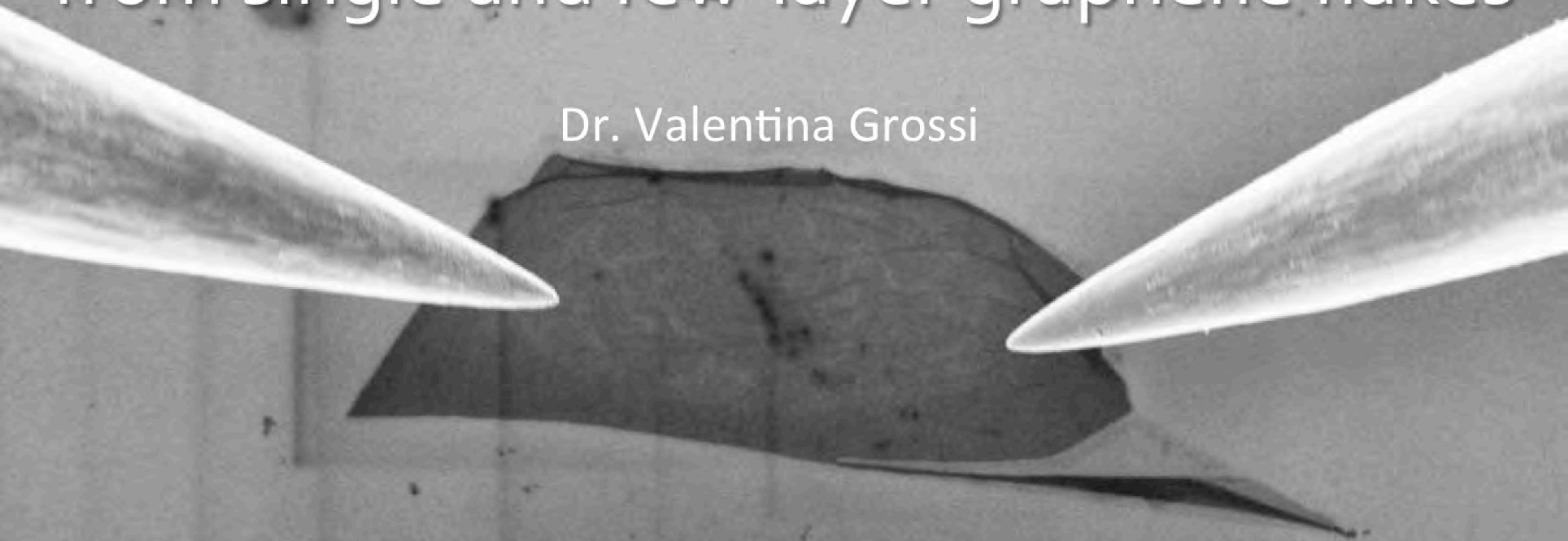




Field emission from single and few-layer graphene flakes

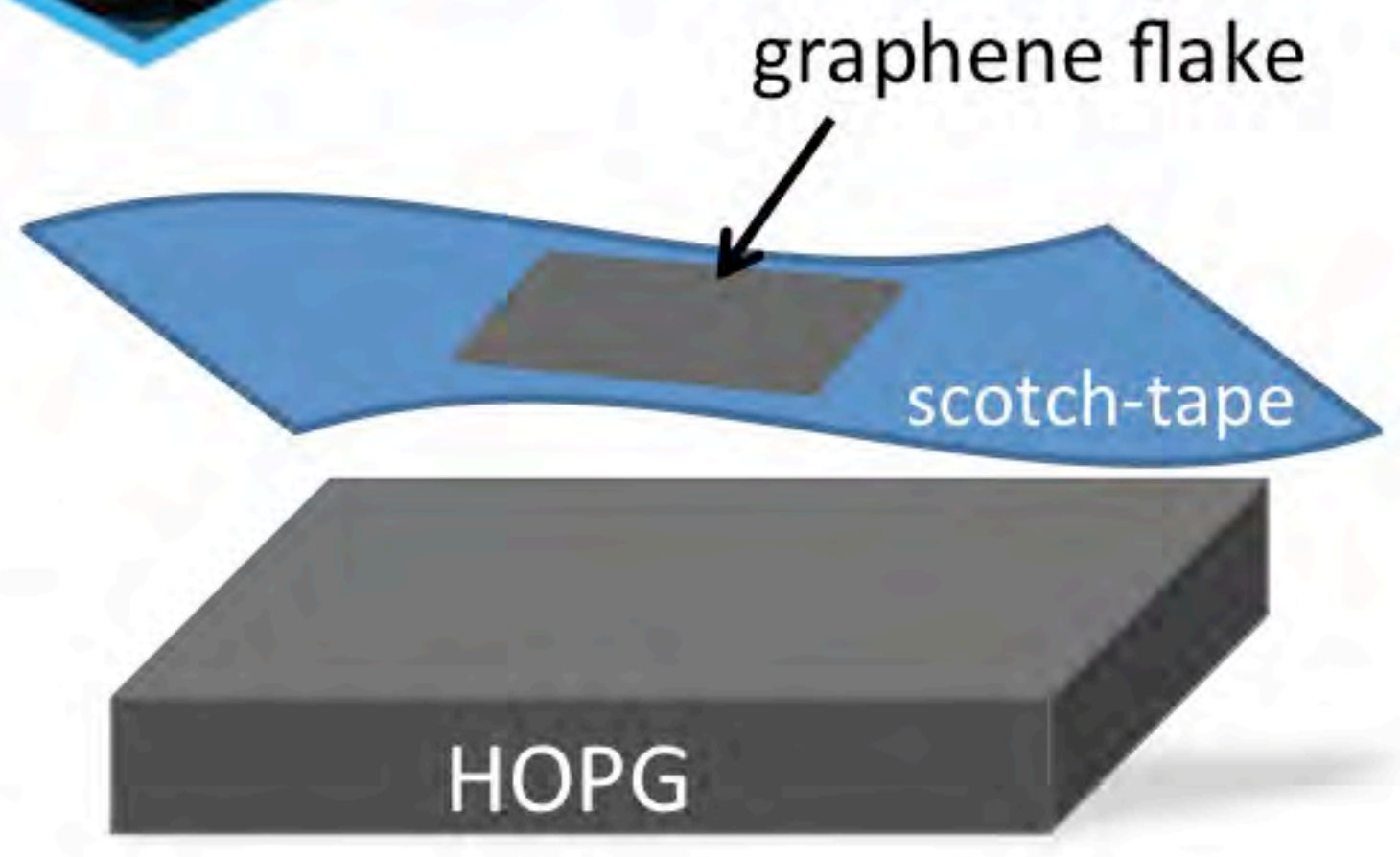
Dr. Valentina Grossi



S. Santandrea, F. Giubileo, V. Grossi, S. Santucci, M. Passacantando, T. Schroeder,
G. Lupina, and A. Di Bartolomeo
APPLIED PHYSICS LETTERS **98**, 163109 (2011)



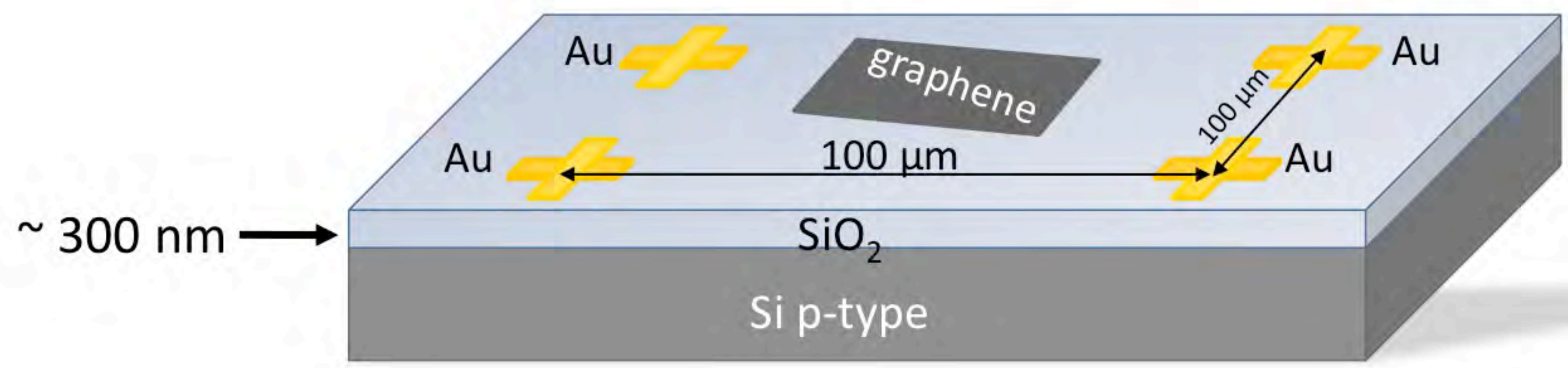
Production of graphene flakes



Mechanical exfoliation of HOPG



Transfer by scotch-tape method

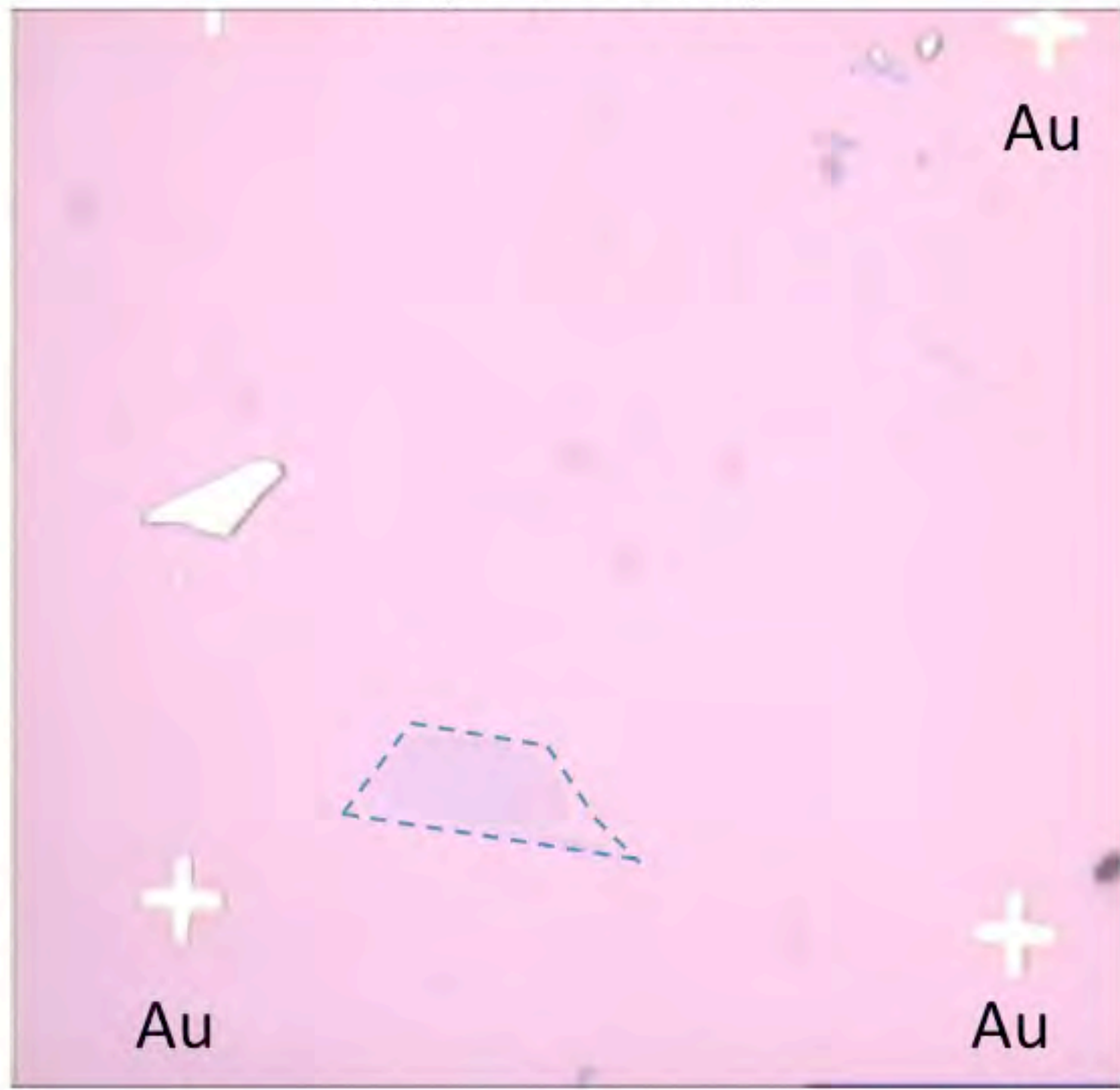




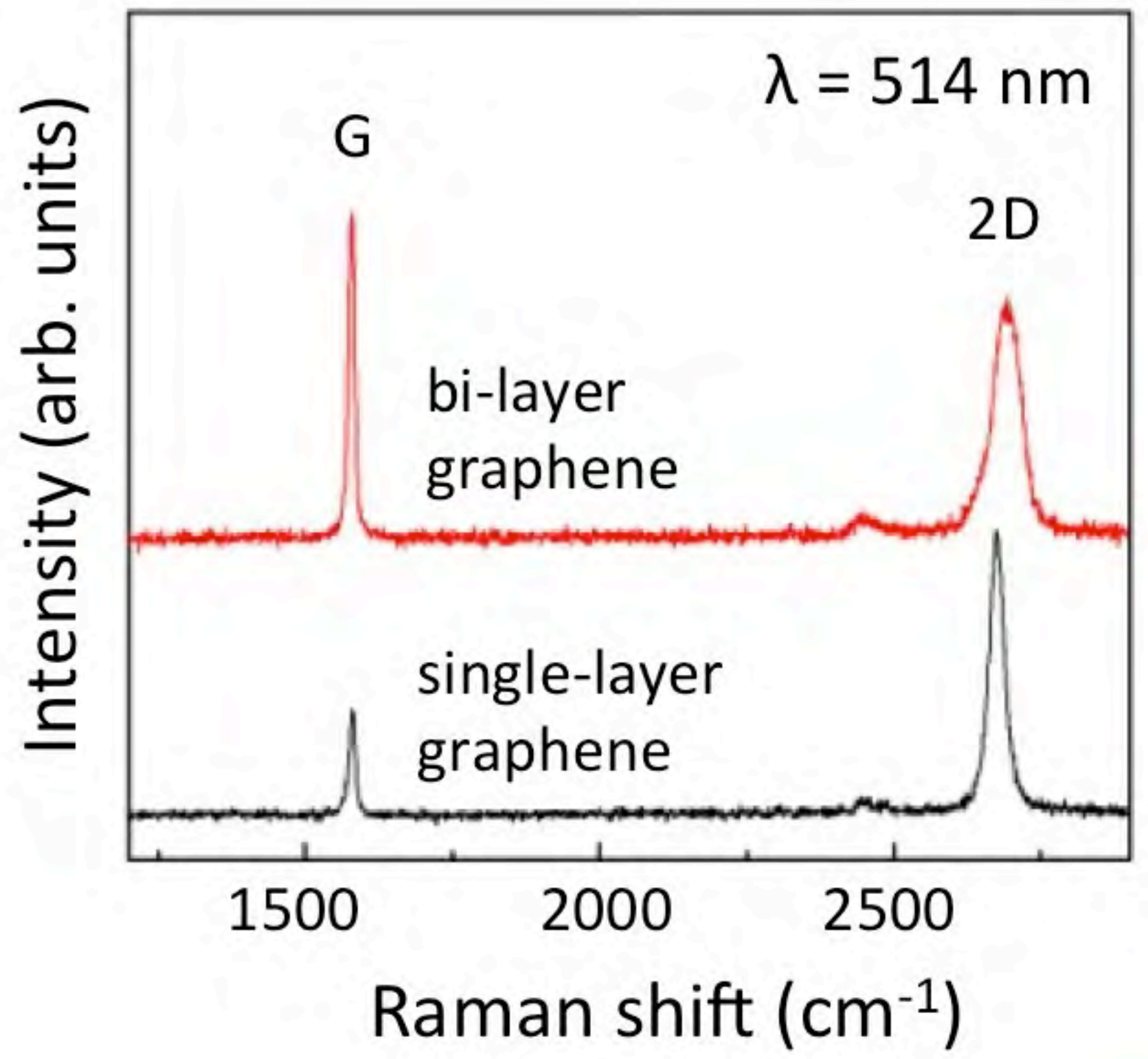
Identification of graphene flakes

Optical image

(objective 50 X)



Raman spectra





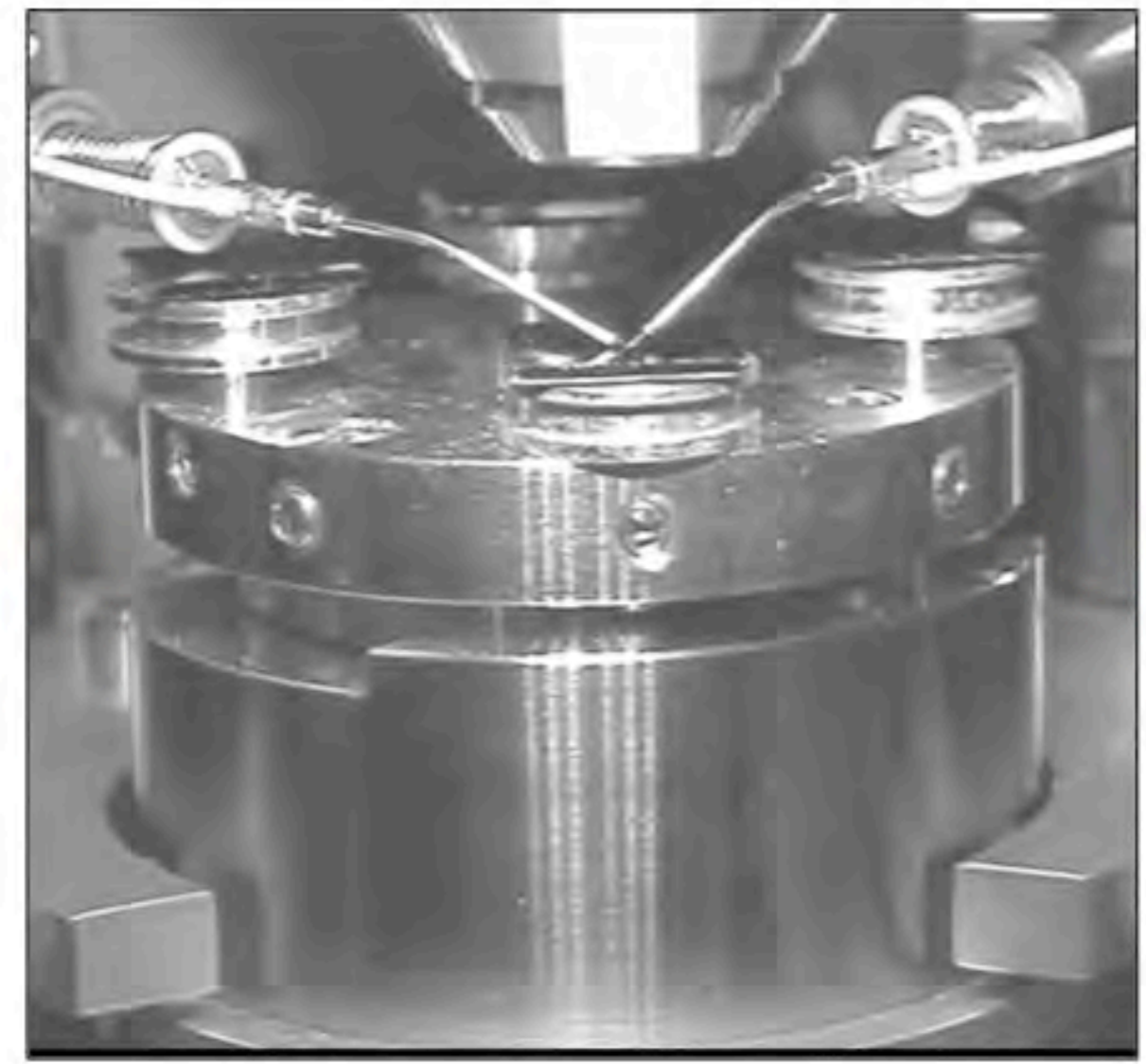
Experimental setup for Field Emission measurements

Nanomanipulator

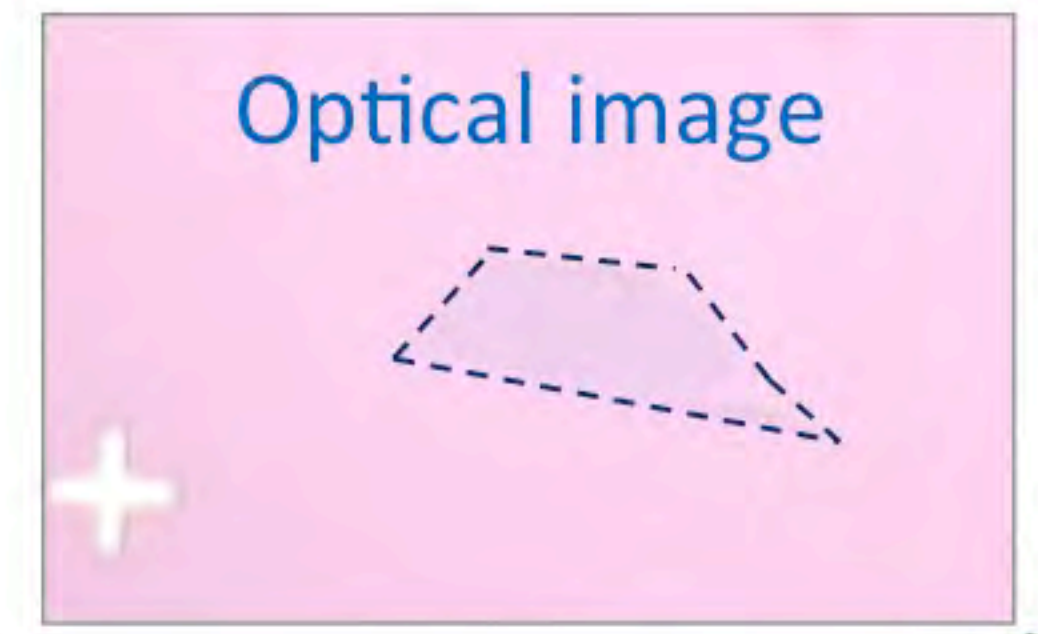
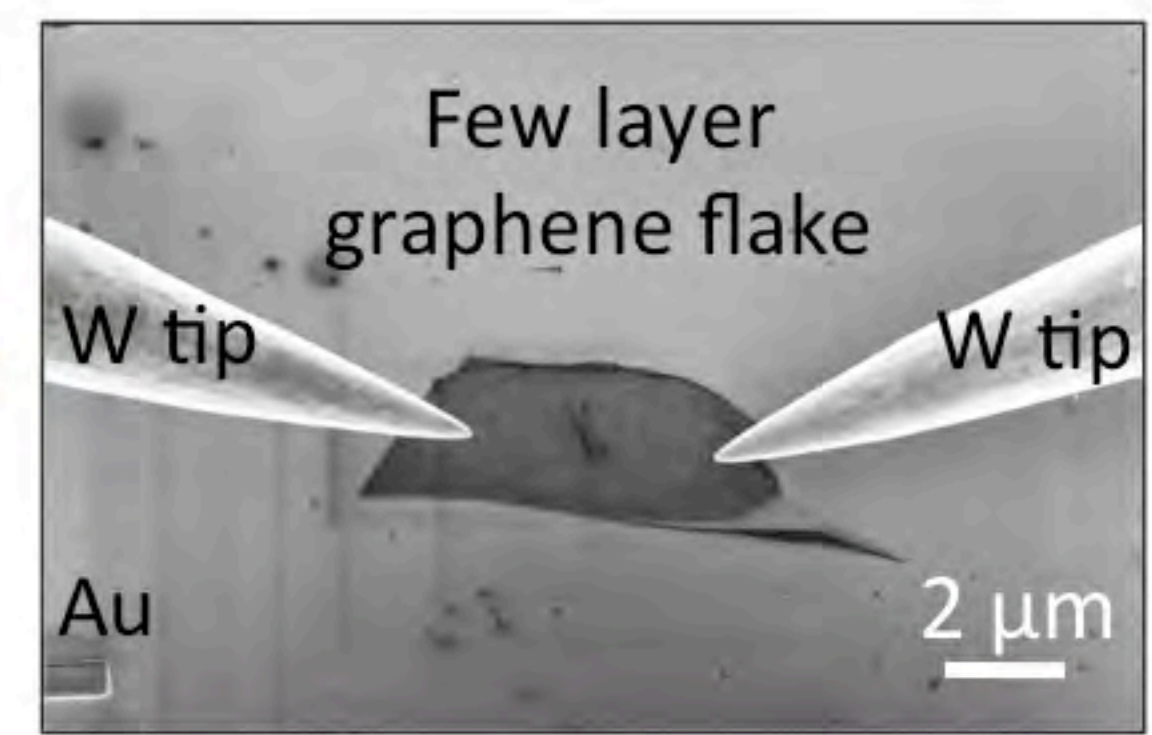


tungsten (W) tip
curvature radius
< 100 nm

SEM chamber

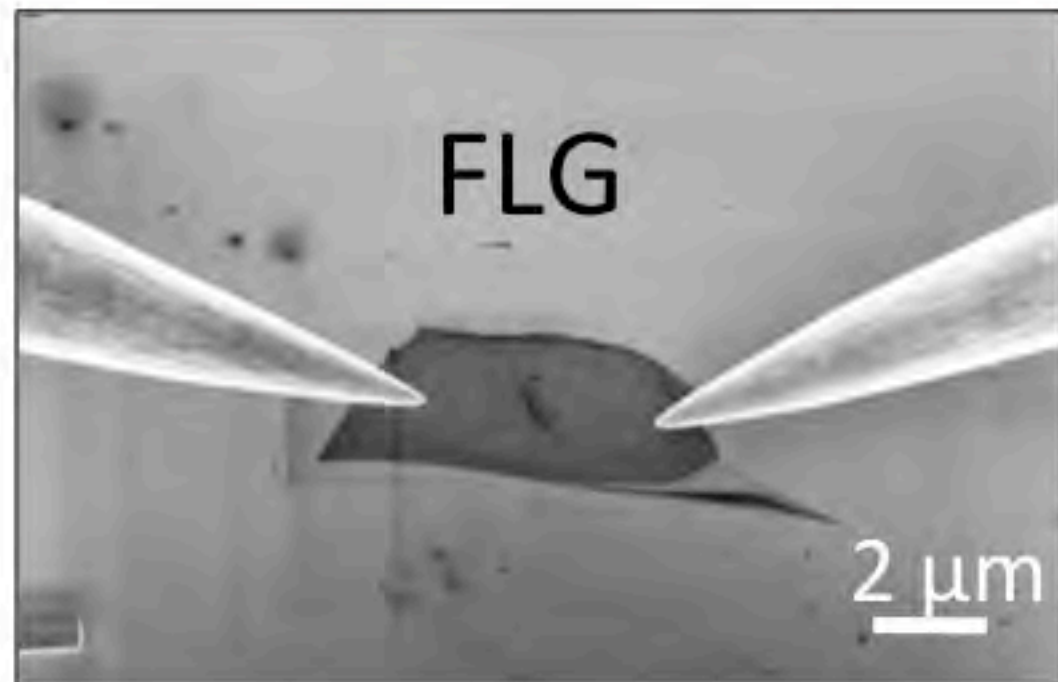
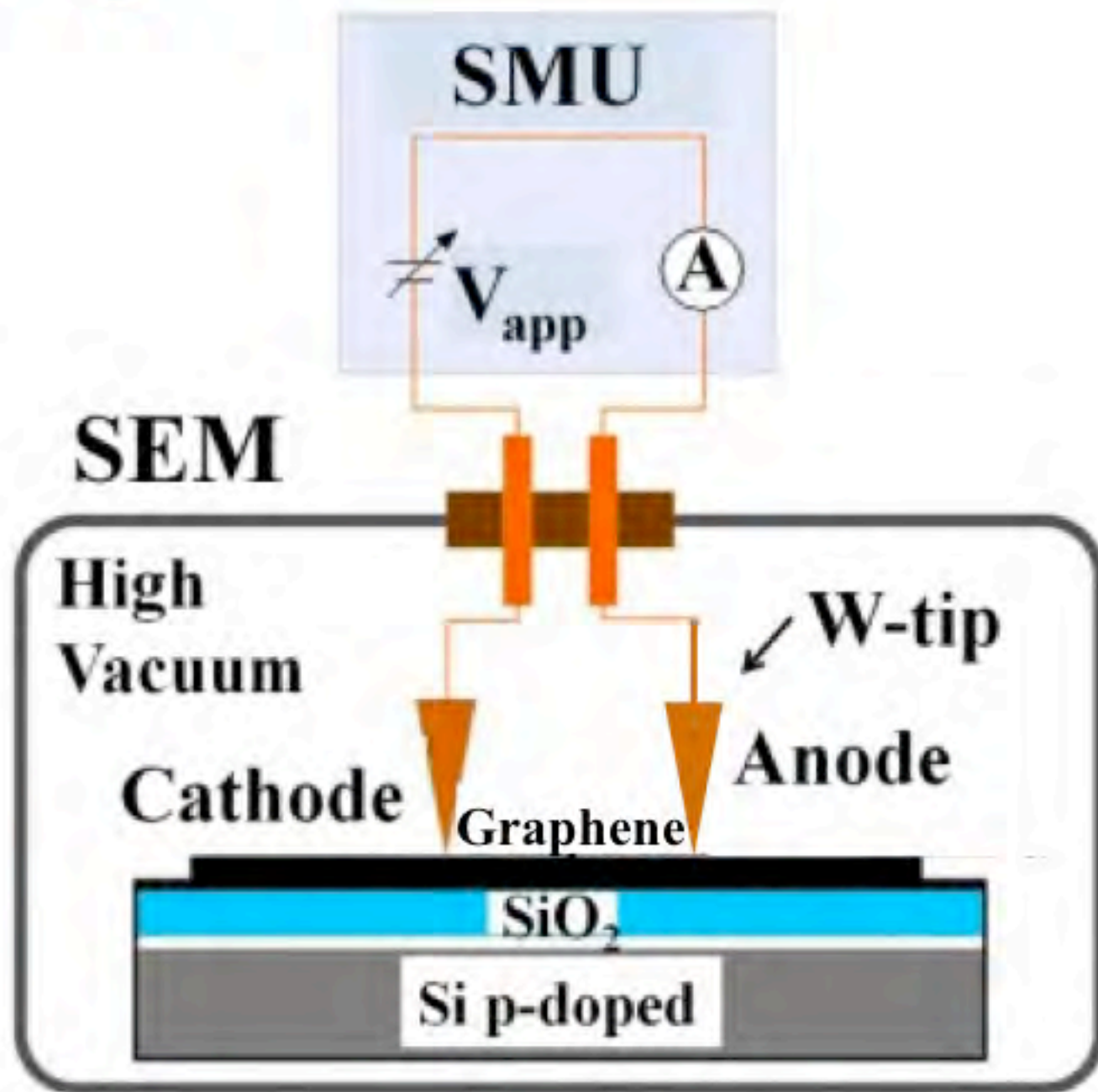


SEM image

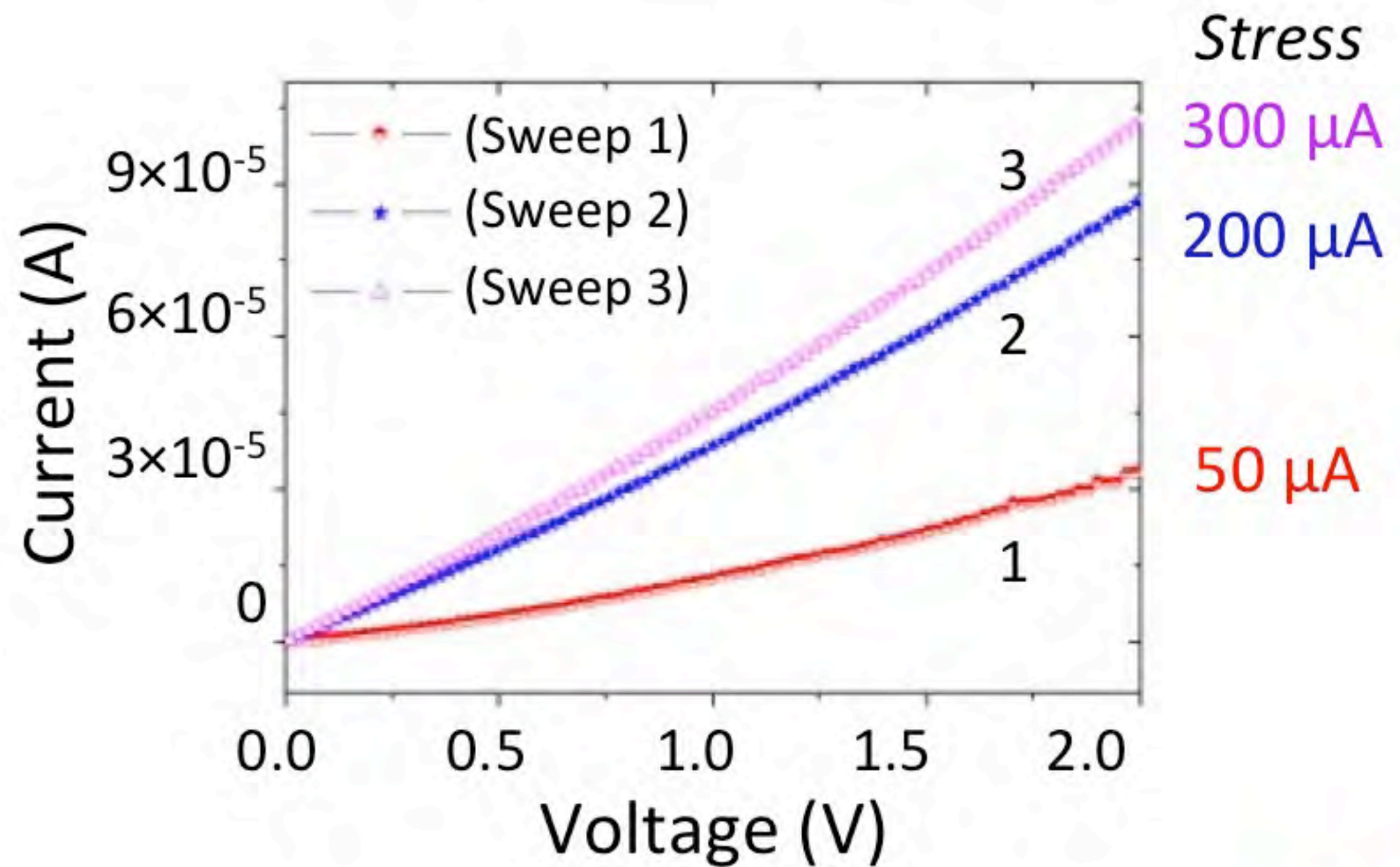




I-V characteristics of graphene flakes

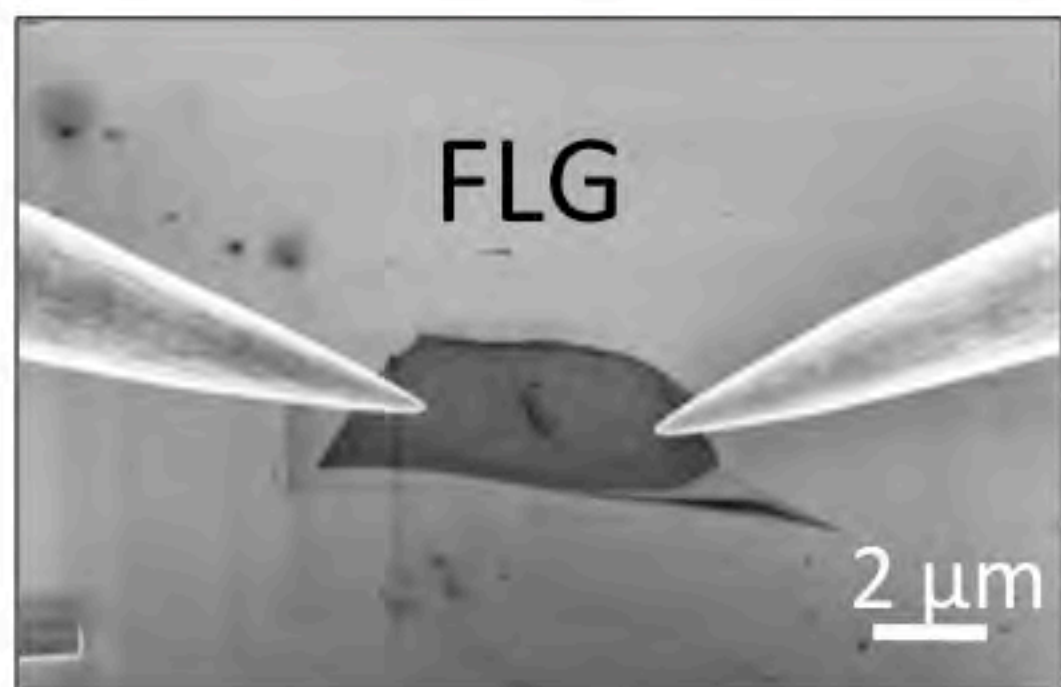
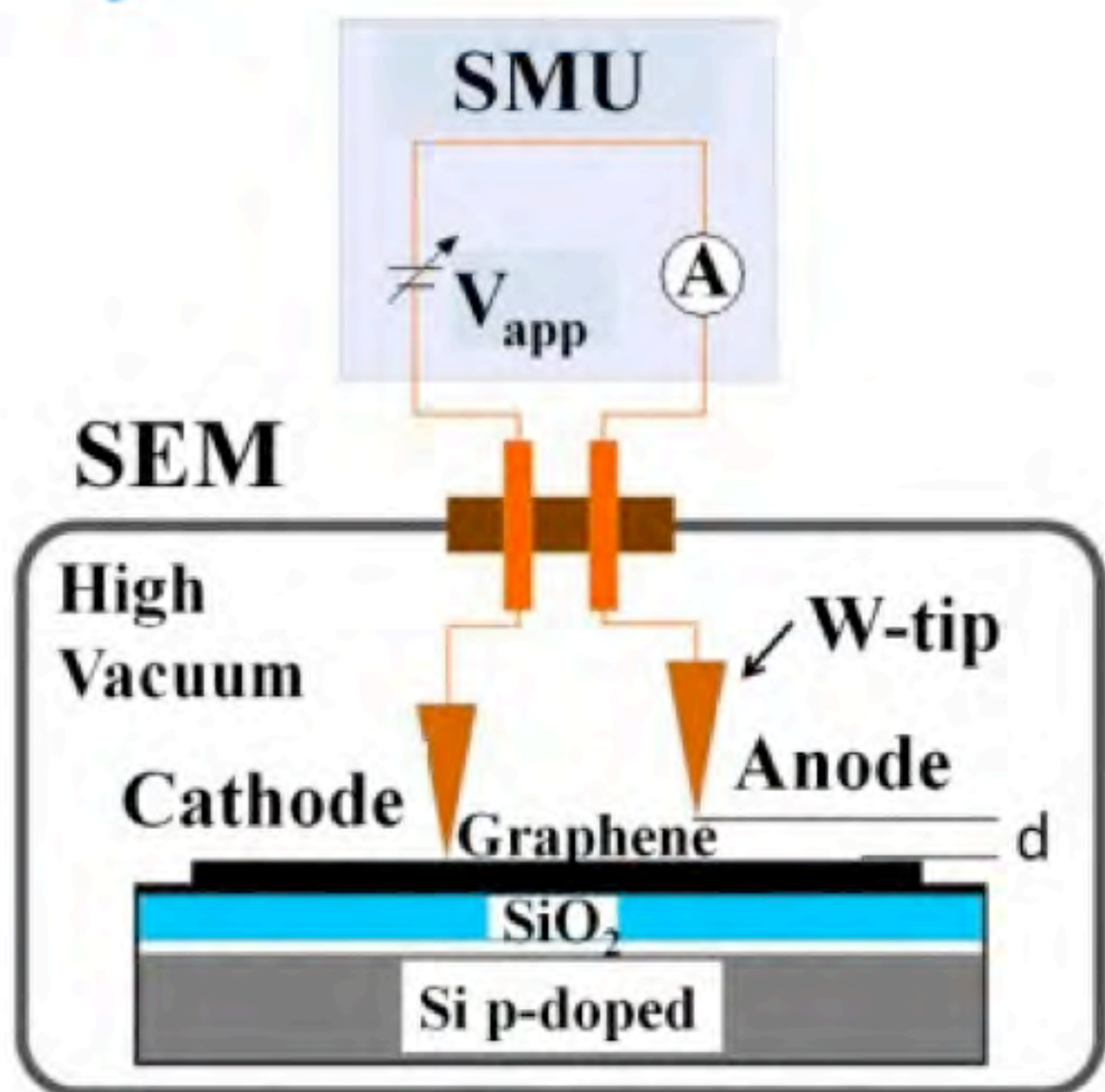


- Short circuit resistance: $R = 3 \Omega$
- System resistance: $R = M\Omega \rightarrow k\Omega$
after successive voltage sweeps

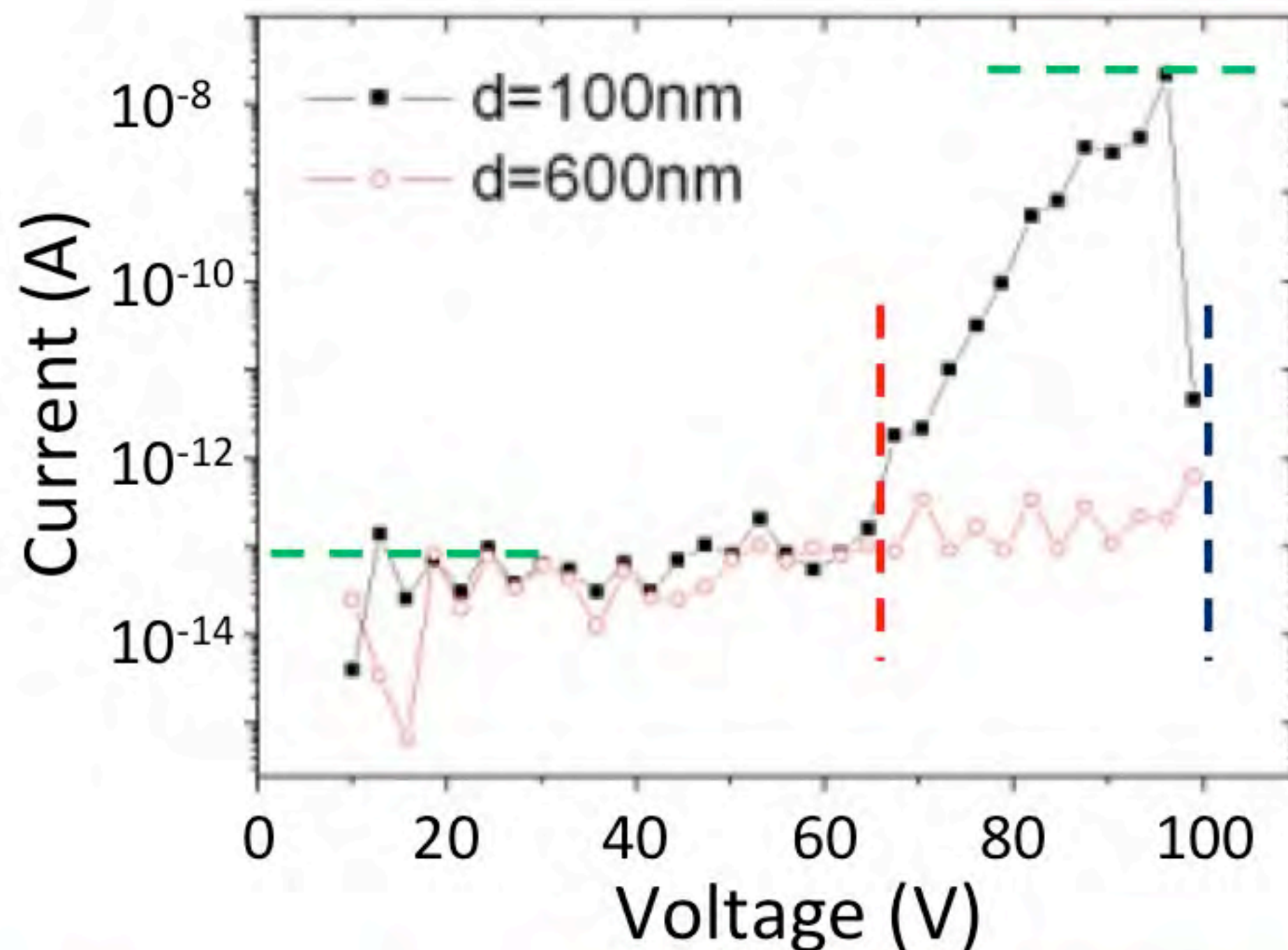




Field Emission from a FLG flake



$V = (0-200) \text{ V} , I_{\text{max}} = 10 \mu\text{A}$



FE start: $V > 60 \text{ V} , E_{\text{on}} \sim 600 \text{ V}/\mu\text{m} \rightarrow 10 \text{ pA}$

$$I_{\text{FE}} \sim I_0 \times 10^5$$

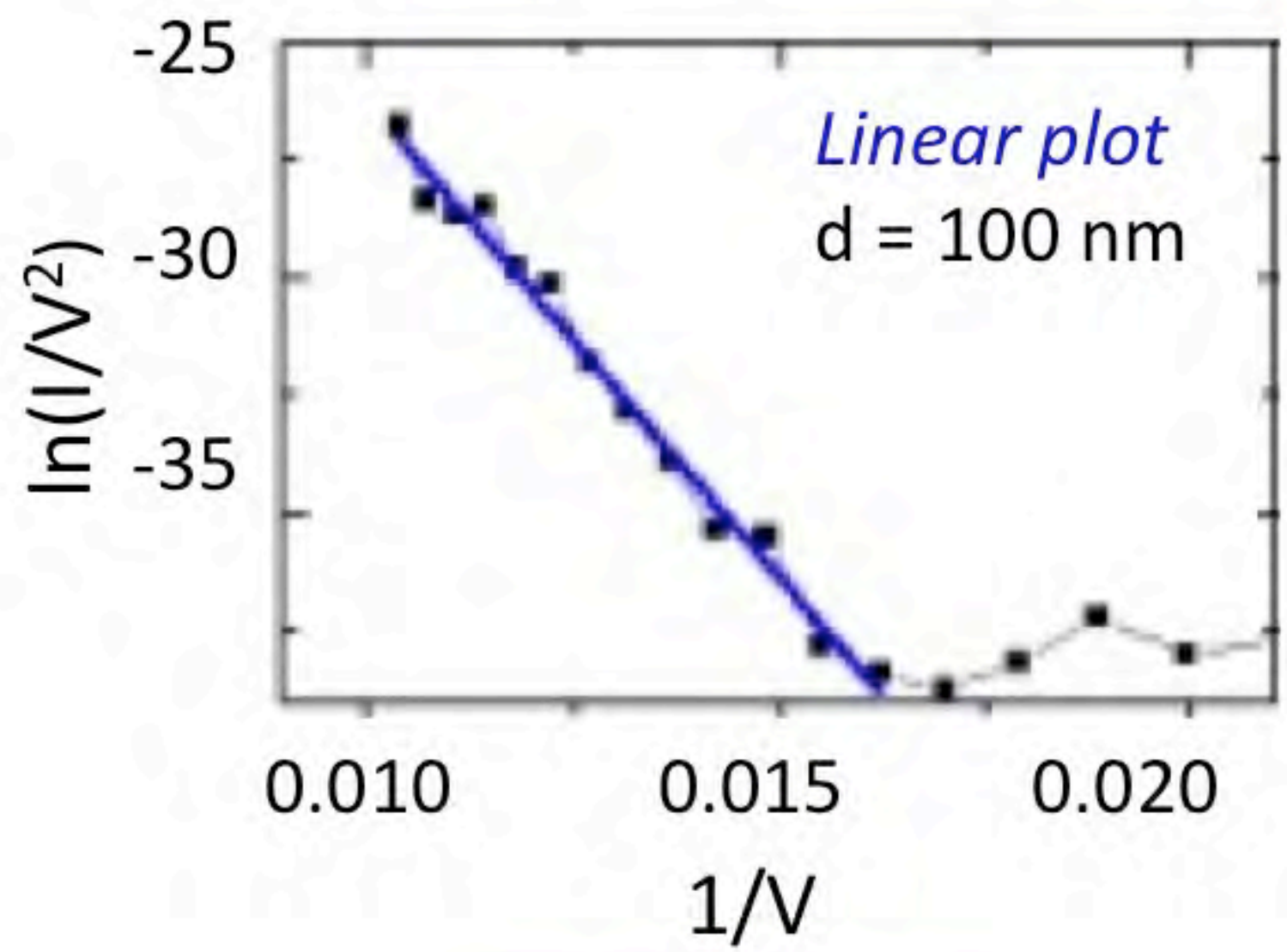
FE break: $V \sim 100 \text{ V}$





Field Emission from a FLG flake

FE current from a flat graphene layer can be described by *standard Fowler-Nordheim model*



$$I = S \frac{a\beta^2 E^2}{\Phi} \exp\left(-\frac{b\phi^{3/2}}{\beta E}\right)$$

- $E = \frac{V}{d}$: electric field
- β : field enhancement factor
- S : emitting surface
- Φ : work function of the emitting material
- $a = 1.54 \times 10^{-6} \text{ A eV V}^{-2}$
- $b = 6.83 \times 10^7 \text{ eV}^{-3/2} \text{ V cm}^{-1}$

$$\ln\left(\frac{I}{V^2}\right) \propto \frac{1}{V}$$



~~$$\ln\left(\frac{I}{E^\alpha}\right) \propto \frac{1}{E^\beta}$$~~

FE from the *edges* of graphene flake

Z. Xiao et al., ACS Nano 4, 6332 (2010)

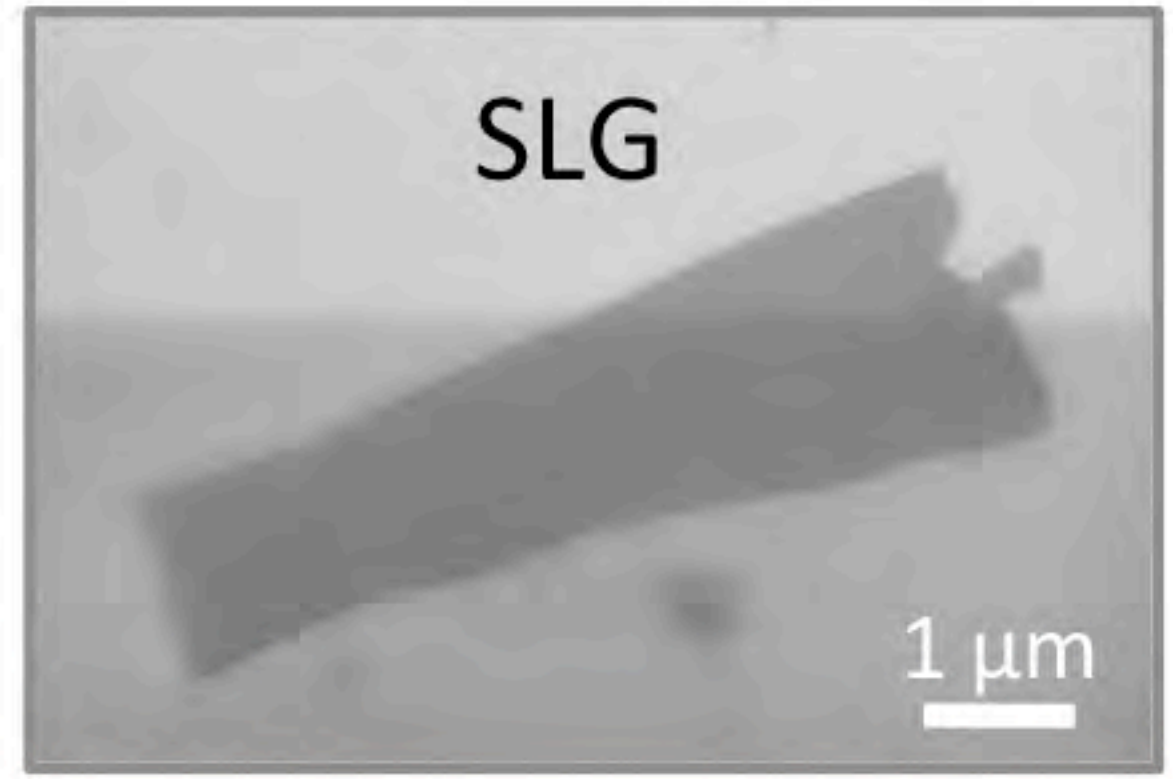
the *linear plot* confirms a FE current



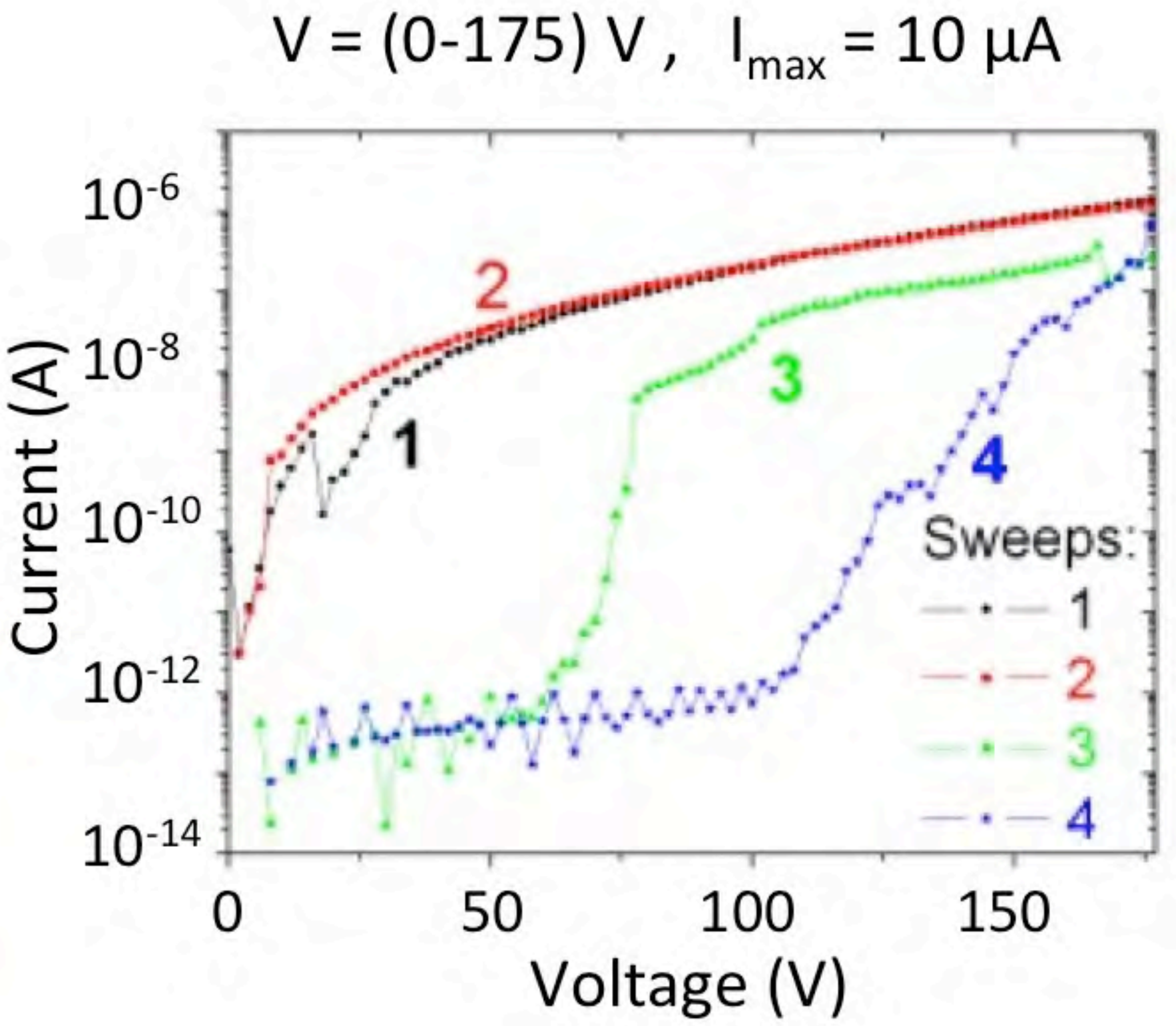


Field Emission from a SLG flake

SEM image



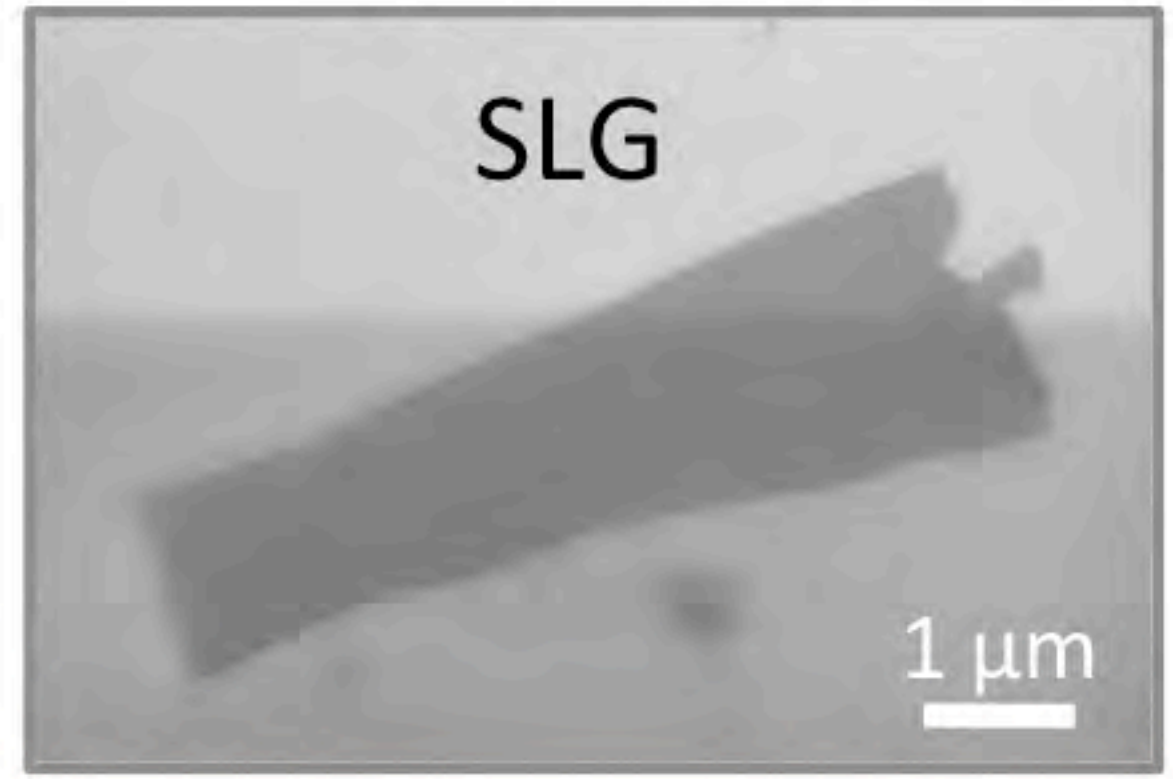
Sweep	d (nm)	FE start	FE break
1	10	-	-
2	20	-	-
3	30	>55 V	75 V
4	40	>100 V	175 V



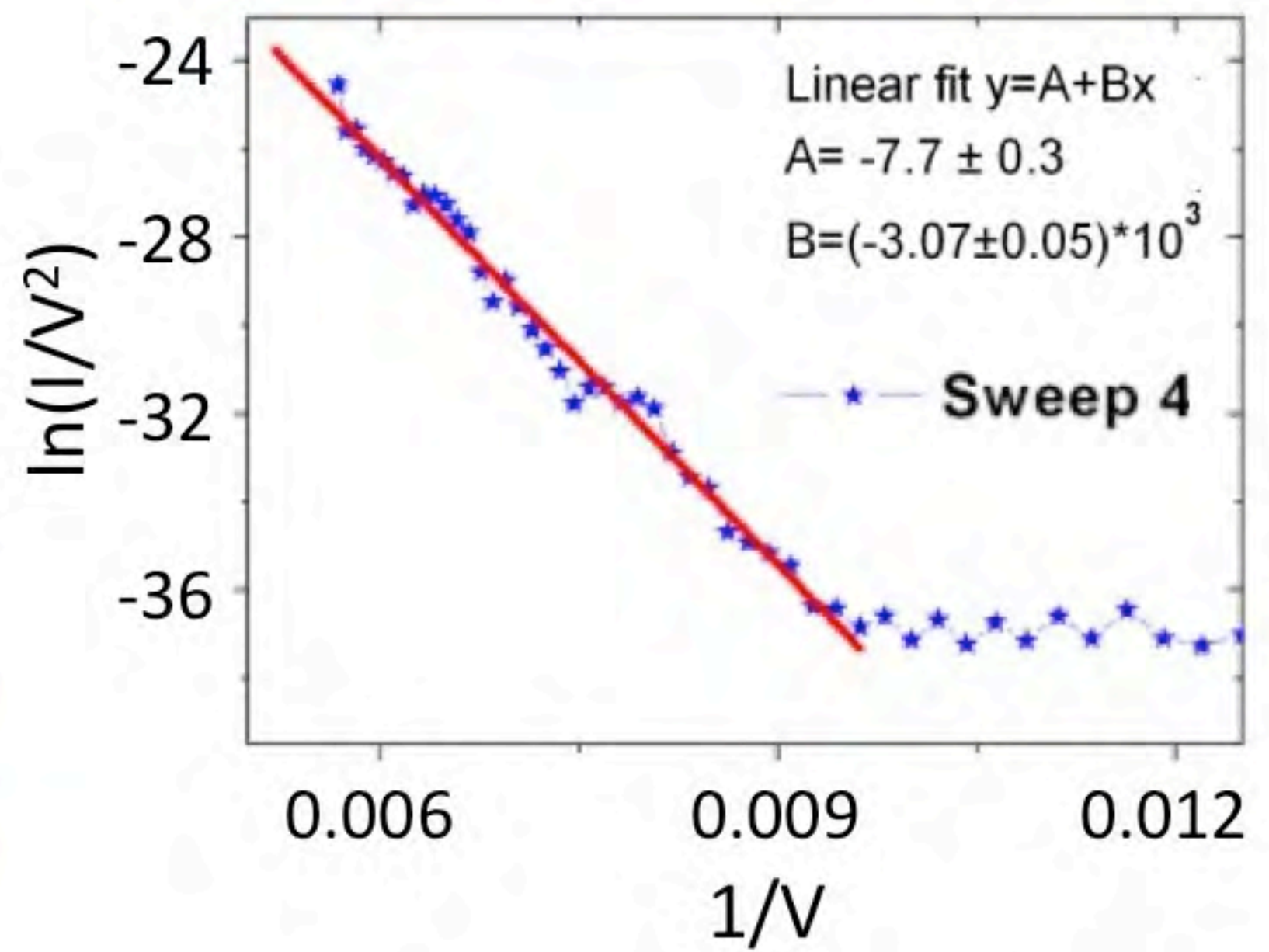


Field Emission from a SLG flake

SEM image



Linear Fowler-Nordheim plot



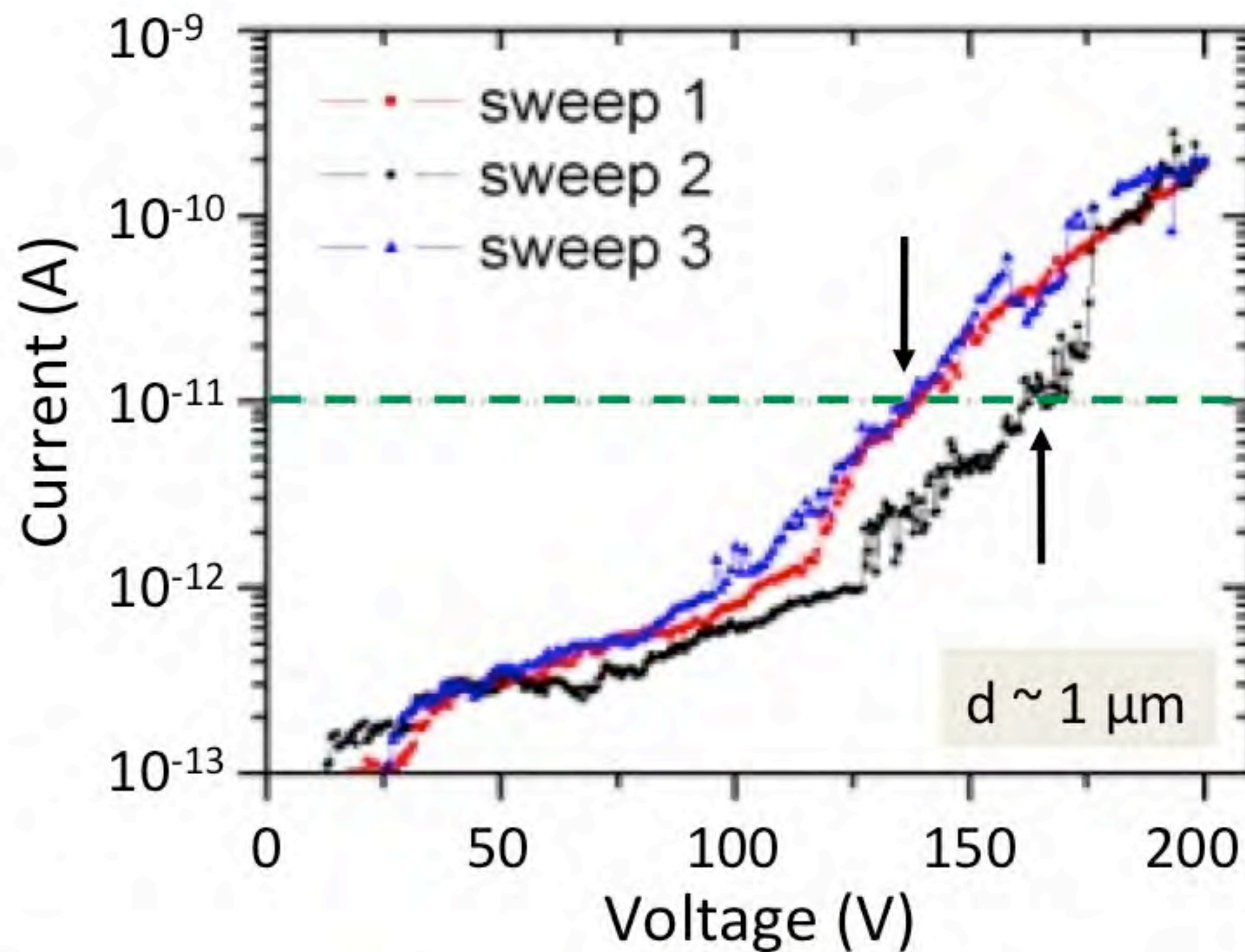
Sweep	d (nm)	FE start	FE break
1	10	-	-
2	20	-	-
3	30	>55 V	75 V
4	40	>100 V	175 V

$\ln\left(\frac{I}{V^2}\right) \propto \frac{1}{V}$
↔
Field Emission inner part SLG





Field Emission from a SLG flake for successive sweeps



FE current achieves a *stable common value* at high fields $\rightarrow V \sim 175 \text{ V}$

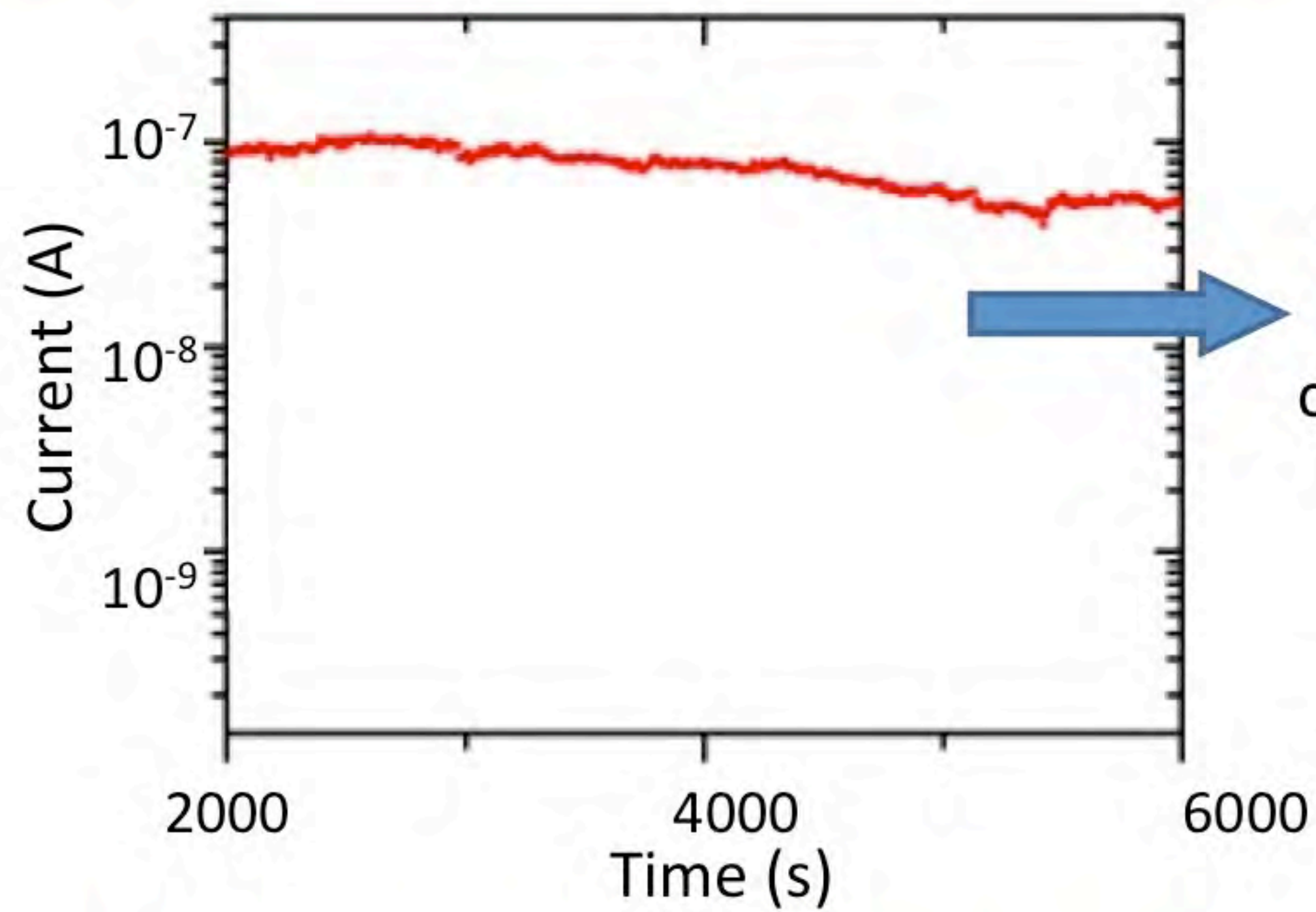
Successive sweeps *reduce* the *turn-on field*: $E_{\text{on}2} \sim 160 \text{ V}/\mu\text{m} \rightarrow E_{\text{on}3} \sim 130 \text{ V}/\mu\text{m}$





Field Emission stability from a SLG flake

Voltage	Time	Step	I	Distance SLG-anode
100 V	2h	10s	$\sim 10^{-7}$ A	adjusted



Over a time of 2h the **thermal drift** causes a **d increase**

Current decrease

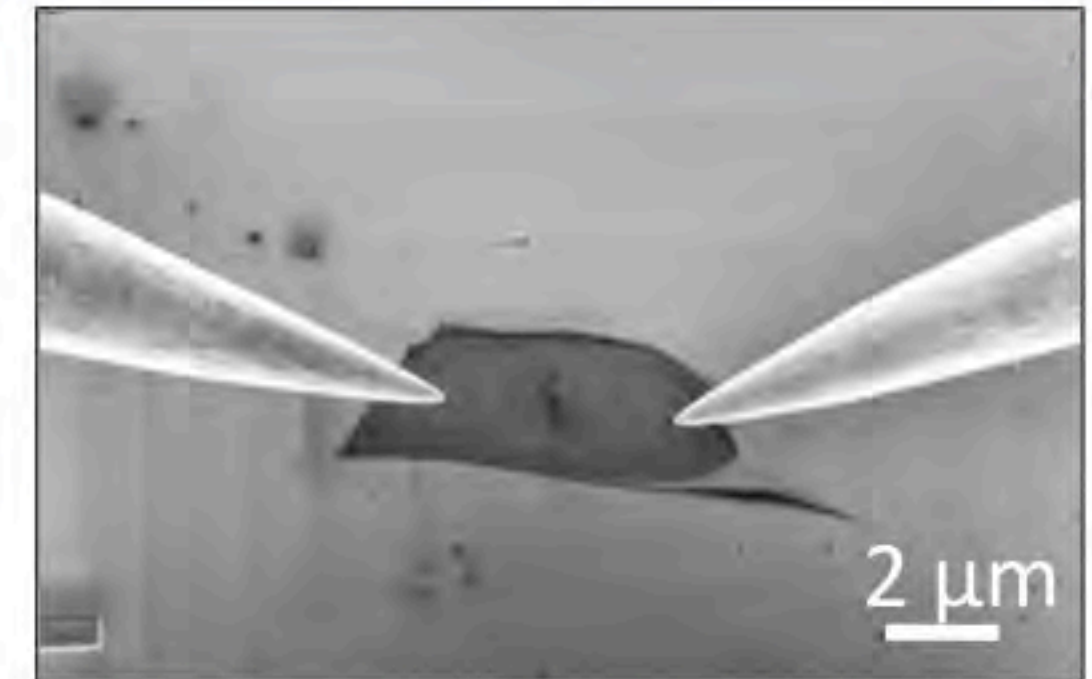
A good stability was obtained!





Conclusions

- Observation of *Field Emission current from the inner, flat part* of single- and few-layer graphene.



- The *current* can reach values up to $1 \mu A$ with a E_{on} of $600 V/\mu m$.

- *Field Emission current* follows the *Fowler-Nordheim model* over five orders of magnitude.

- *Field Emission current* has been monitored for *few hours*, over which (2h) a *stable process* was confirmed.





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