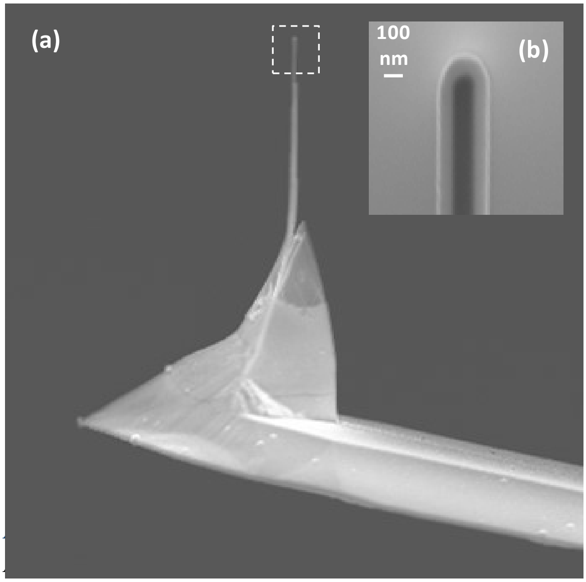
NN NAUGANEEDLES™

NaugaNeedles' Encapsulated Nano Electrode (ENE)

NaugaNeedles offers Encapsulated Nano Electrode (ENE) applicable in scanning gate microscopy (SGM), scanning capacitance microscopy (SCM) and more to study the local electronic properties of a sample. These probes are fabricated by coating a conformal layer of insulating material on a NeedleProbe™ [1]. The preferred insulation material NaugaNeedles apply for this product is parylene which has a high dielectric constant, excellent chemical resistivity, and superior durability for long scanning. Also, the high aspect ratio and cylindrical structure of the Ag_2Ga nanoneedles reduces the parasitic capacitance between the tip and the sample.

These probes can be fabricated with the required specification (considering the inherent constraint) in terms of length and diameter of nanoneedle and insulation material and thickness. ***Figure 1*** shows the SEM images of an ENE with a 10µm nanoneedles coated with 50nm parylene. This probe can perform a localized top gate with a consistent and durable performance over a wide scanned area as well as applied voltage without leakage. The parylene insulating film provides a fixed distance between the gate and the sample during the scan without drifting.

The thinner parylene coating, results in a smaller electrode size, however the applied voltage limit decreases to avoid the parylene break down voltage.



ENE tip with parylene insulation.

A Case Study Using ENE for Scanning Gate Microscopy

As one example for the ENE probes application, ***Figure 2a***, shows the schematic of an experimental setup to measure electrical transport through graphene field effect transistor (GFET) using NaugaNeedles ENE device on an AFM system. In this experiment a biased ENE in contact mode is used as a local top gate and explores the electrical transport through graphene. The SEM image in ***Figure 2b,c*** displays the length and diameter and the parylene coating of an ENE device used for this experiment.

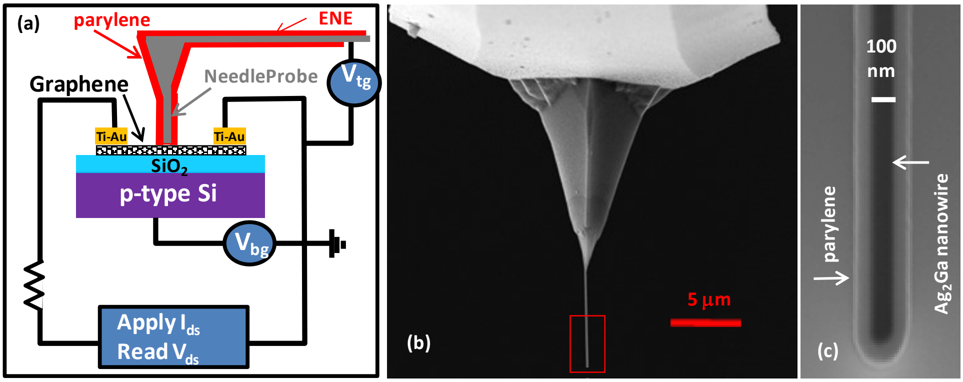


Figure 2: (a) schematic of the scanning gate microscopy experimental set up on a graphene field effect transistor using the NaugaNeedles ENE probe. (b & c) the SEM image of an ENE probe and the end of nanoneedle with ~100nm parylene coating.

In this experiment [2] scientist discovered that near the Dirac point (at V_{DP}), the response of graphene resistance to ENE tip voltage shows significant variation with tip position. Electrical transport through graphene at various backgate voltages was monitored as functions of tip voltage and tip position. The SGM imaging displays mesoscopic domains of electron-doped and hole-doped regions. These measurements reveal substantial spatial fluctuation in the carrier density in graphene due to extrinsic local doping from sources such as metal contacts, edges of graphene, structural defects and resist residues.

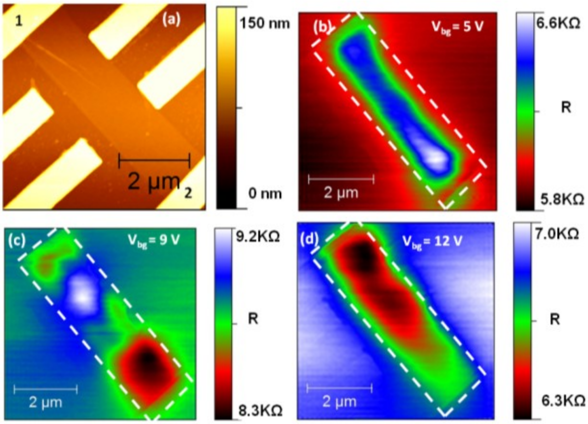


Figure 3: The SGM images of a GFET in figure (a) has been studied at different back gate voltages of (b) Vbg < VDP, (c) Vbg = VDP, and (d) Vbg > VDP. These SGM imaging data were taken at a fixed tip voltage.

Figure 3 presents the results of SGM imaging on a GFET (with a global V_{DP}~9V) measured at a constant V_{tg} (20V) at various V_{bg}. The AFM tapping mode image of this device using an ENE is shown in ***Figure 3a***. ***Figure 3b-d*** display the SGM images for V_{bg}=5V, 9V and 12V respectively. In ***Figure 3b***, where V_{bg}= 5V (<V_{DP}), placing the tip on the p-type graphene is seen to increase its resistance R (by as much as nearly 1 kΩ compared to the background value when the tip is far away from the graphene), with the graphene appearing *blue* (indicating higher resistance than background) in the SGM image. This is due to the local reduction of carriers (holes) density in graphene under the positively biased tip. The opposite behavior is observed in ***Figure 3d***, where V_{bg}= 12V (>V_{DP}) and placing the tip on the n-type graphene decreases R and makes it appear *red* (indicating lower resistance than background) in the SGM image.

Advantages of ENE:

- Flexible high aspect ratio probe
- Applicable for SGM, SCM and more.
- A high break down voltage for insulating layer on the probe
- Low capacitive parasitic behavior during electrical measurement

References

1. www.nauganeedles.com/products
2. Jalilian, et al., "Scanning gate microscopy on graphene: Charge inhomogeneity and extrinsic doping " *Nanotechnology,* 22 (2011) 295705.