Hot-electron nanoscopy using adiabatic compression of surface plasmons

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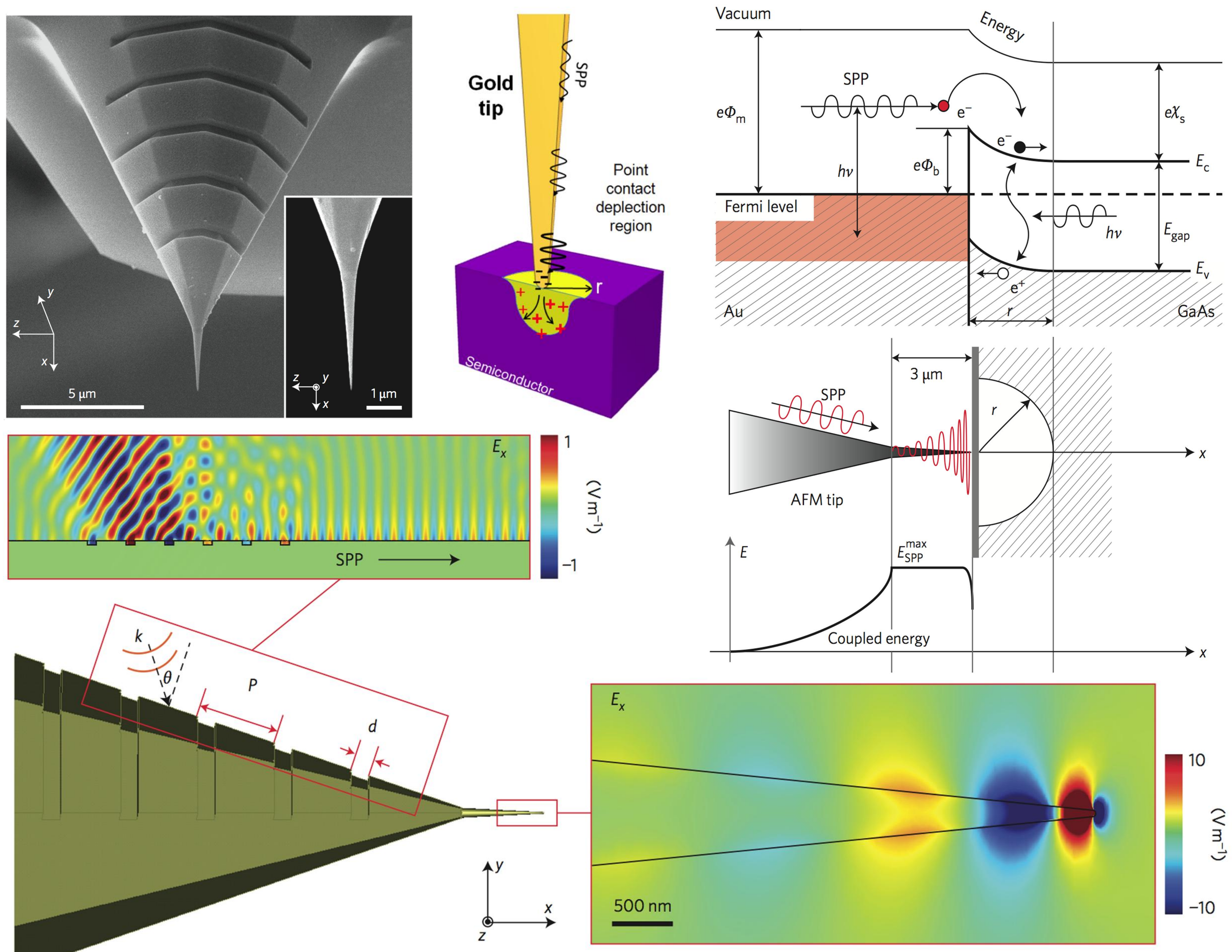
Motivation:

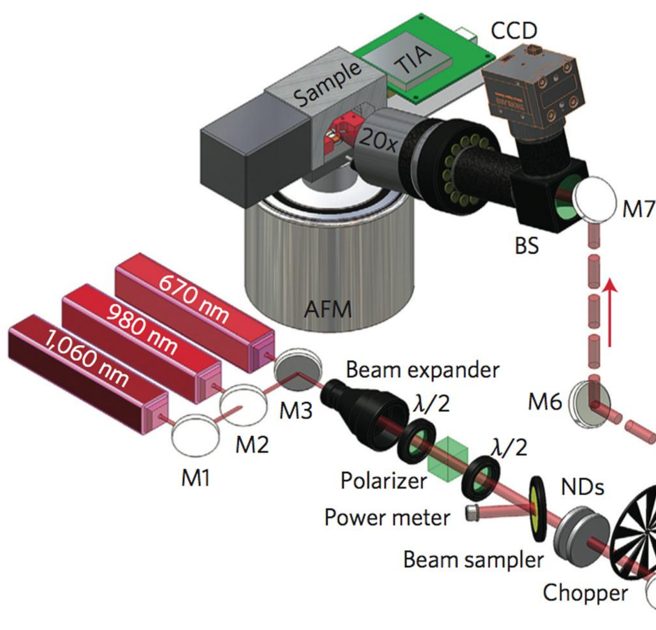
Surface plasmon polaritons can decay to form highly energetic (or hot) electrons in a process that is usually thought to be parasitic, in fact it limits the lifetime and propagation length of surface plasmons. However, it has been recently shown that hot electrons produced by surface plasmon decay can be harnessed to produce useful work in photo-detection, catalysis and solar energy conversion [1, 2]. Here we show that adiabatic focusing of surface plasmons on a Schottky diode-terminated tapered tip of nanoscale dimensions allows for a plasmon-to-hot-electron conversion efficiency of ~30%. We further demonstrate that, with such high efficiency, hot electrons can be used for a new nanoscopy technique based on an atomic force microscopy set-up. We show that this hot-electron nanoscopy preserves the chemical sensitivity of the scanned surface and has a spatial resolution below 50 nm, with margins for improvement [3].

1. Adiabatic tip and Surface Plasmon generation

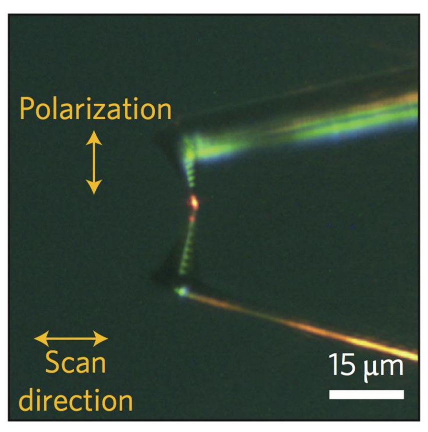


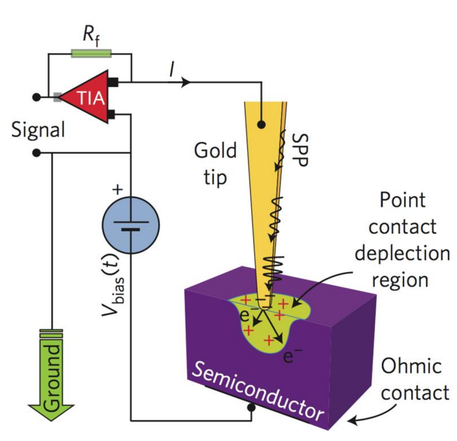
SEM images of the grating and the adiabatic tip. Band diagram at the metal/semiconductor interface showing the energy of the hot electrons generated by SPP decay. A fully 3D simulation was used for calculating the coupling efficiency.

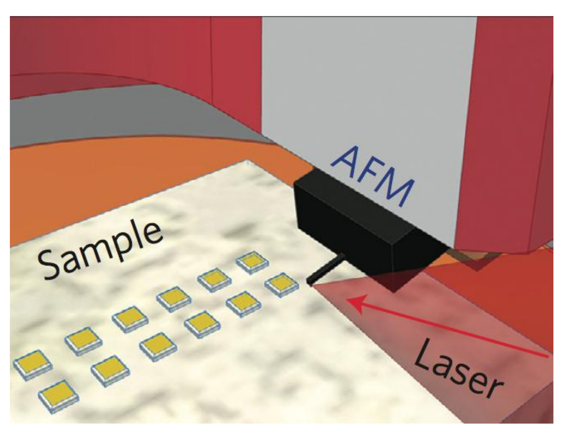
2. Photoelectric current through the GaAs–Au tip junction: SPP-to-hot-electron conversion

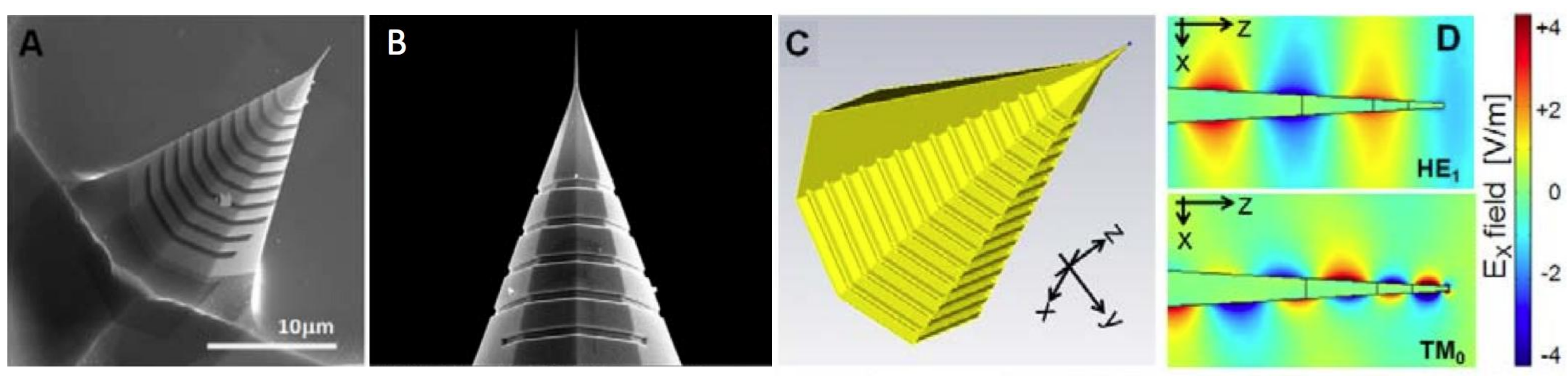


Optical layout: *vertically polarized continuous-wave laser excitation at 670 nm, 980 nm or 1060 nm (10 mW of optical power on the coupling grating) was amplitude-modulated by a mechanical chopper wheel at 500 Hz and focused on the structured AFM tip.*

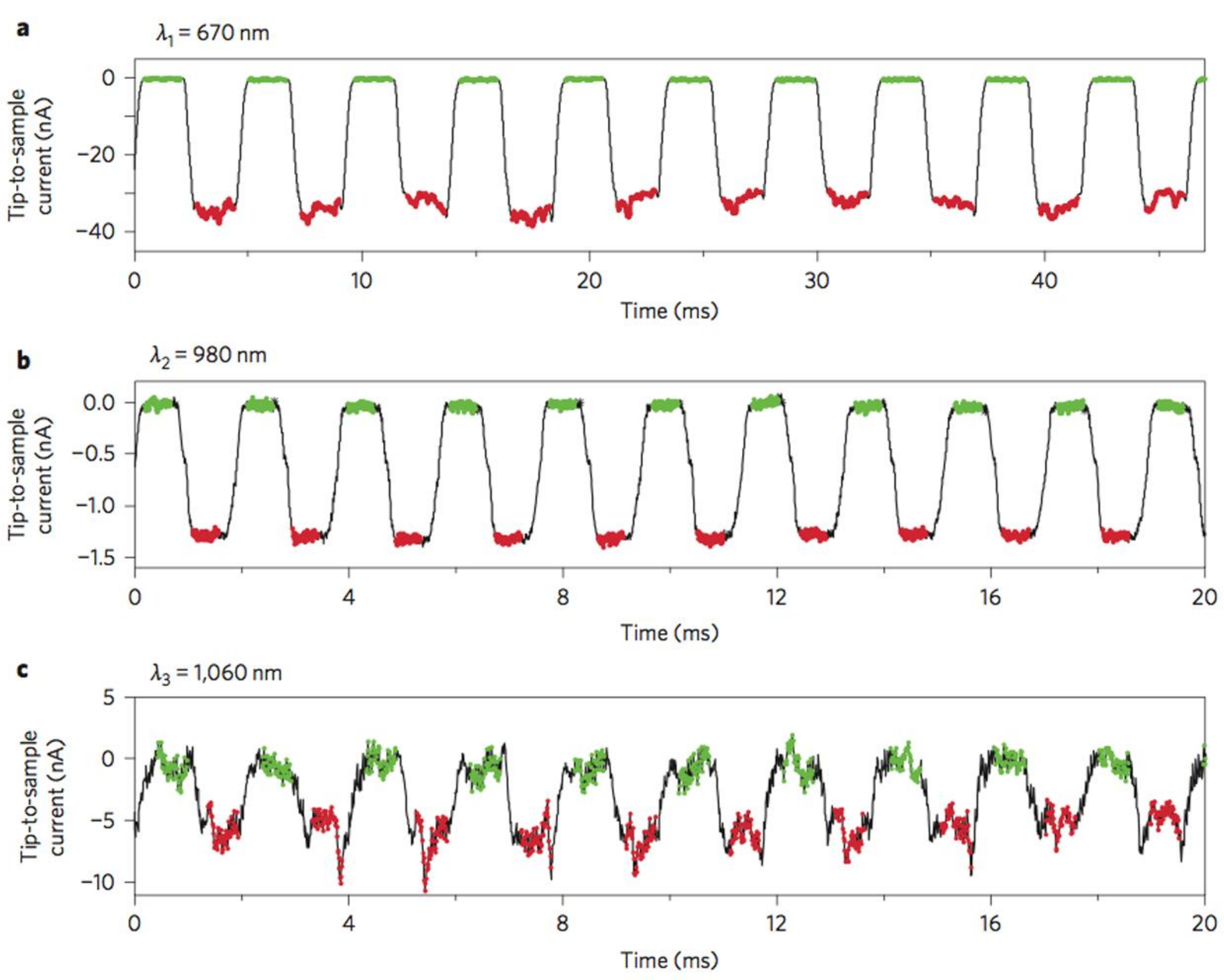






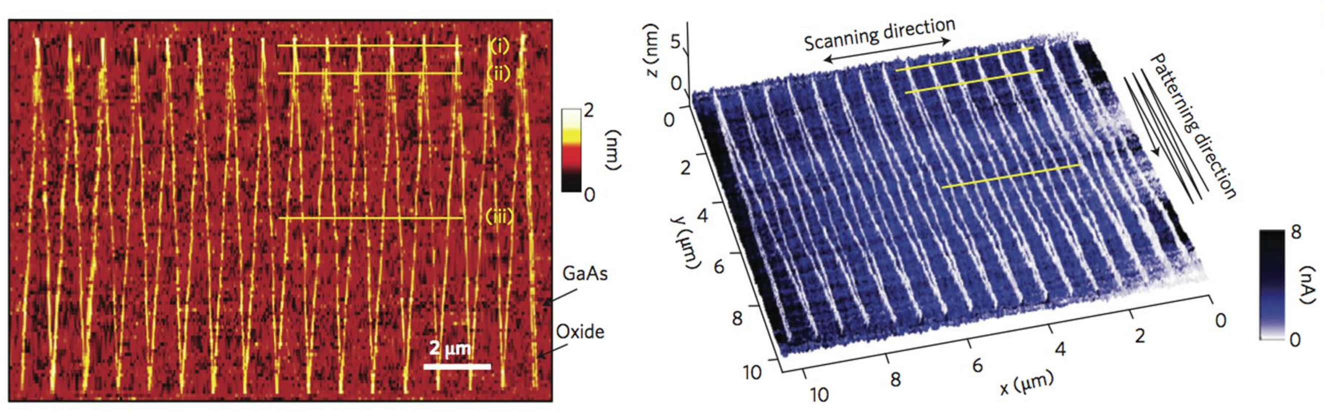


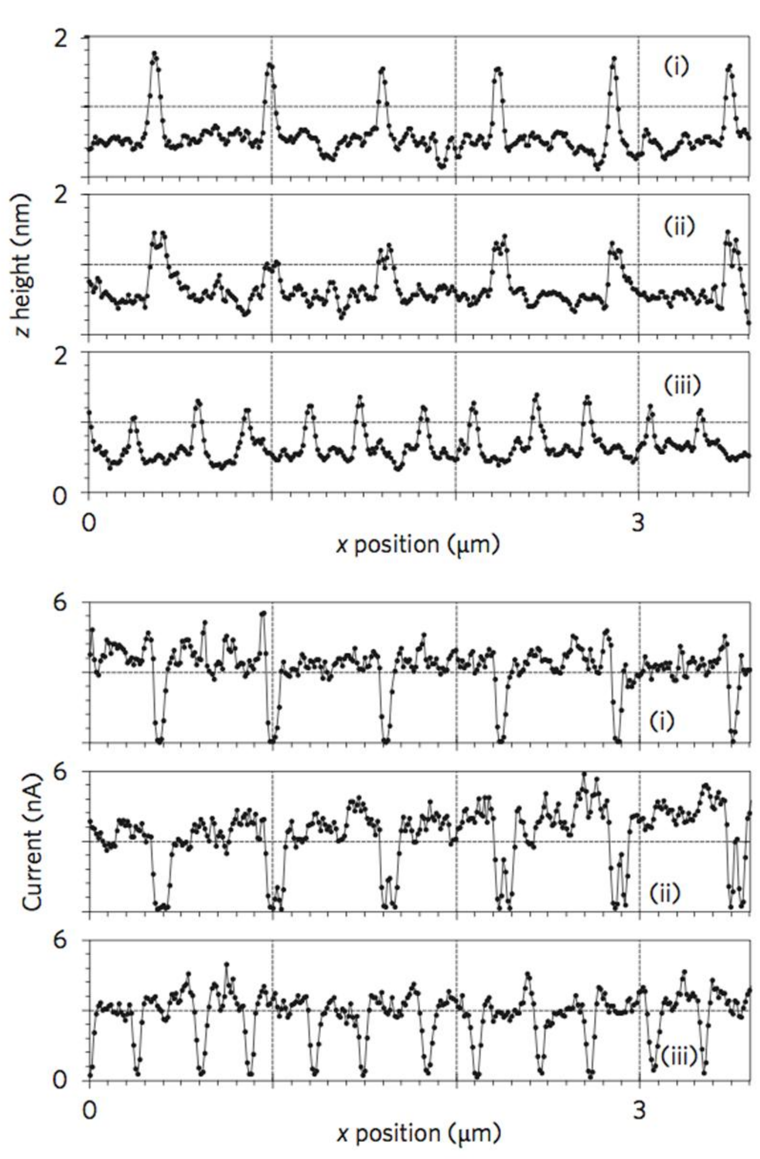
I_{on} and I_{off} measurements through the n-type GaAs–Au tip junction for a fixed bias value of -2 V. **@ 980 nm and 1060 nm only hot-electrons contribute to the photocurrent.**



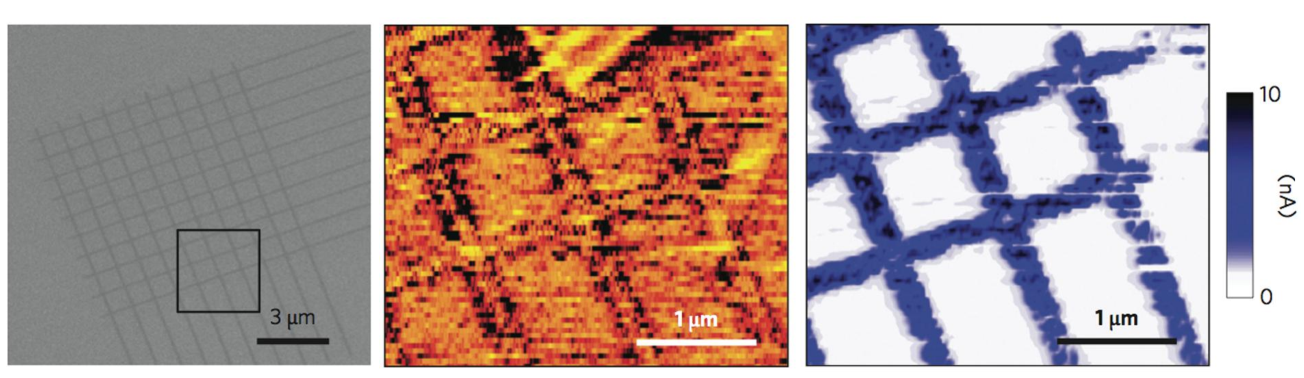
3. Hot-electron nanoscopy: 3D maps of nanopatterns

High-resolution AFM topography and photocurrent maps of a continuous oxide pattern deposited on GaAs through high field discharge in water (40% ambient air humidity).





Topography and plasmonic hot-electron maps (generated at 980 nm laser excitation) acquired on a locally Ga ion-implanted GaAs substrate. This sample shows an increased conductivity due to 30 keV focused implanted ions.



*i. SEM micrograph **ii.** Topography **iii.** Hot-electron map @ 980 nm laser excitation*

hot electrons can efficiently work with very low contrast topography with both oxide and conductive nanopatterned structures.

Conclusion:

The present study demonstrated, as a proof of concept, the relationship between SPPs and the generation of hot electrons, with particular attention for surface imaging with local chemical sensitivity. This approach allowed us to obtain topographic and photocurrent maps of patterned GaAs samples with both thin oxidized nanostructures and ion-implanted lines.

References and Insights:

1) ***An autonomous photosynthetic device in which all charge carriers derive from surface plasmons,*** S. Mubeen, et al. Nature Nanotech. 8, 247 (2013).
2) ***Photodetection with active optical antennas,*** M. Knight, et al. Science 332, 702 (2011).
3) ***Hot-electron nanoscopy using adiabatic compression of surface plasmon***, A. Giugni, B. Torre, A. Toma et al. Nature Nanotech. 8, 845 (2013).