Influence of current-voltage amplification and feedback time constants on THz-STM

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Open-Minded

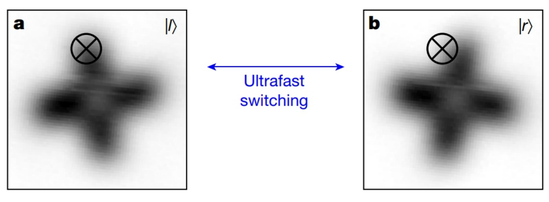
Motivation

Why THz-STM?

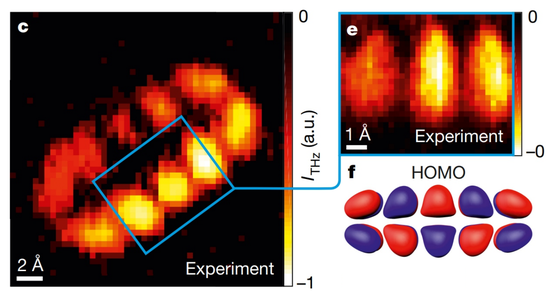
- electric pulses with conventional STM only reach nanosecond resolution
- too slow for many phenomena like vibrations

- THz induces picosecond voltage transients
- pump-probe used for imaging in the time domain

→ combines atomic resolution of STM with femtosecond time resolution of pulsed lasers



Cocker, T., Peller, D., Yu, P. et al. Tracking the ultrafast motion of a single molecule by femtosecond orbital imaging. Nature 539, 263–267 (2016)

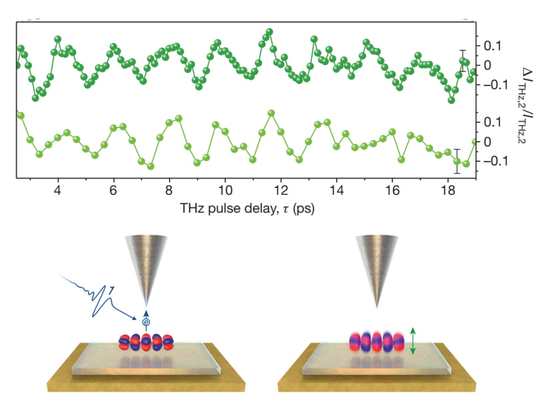


Peller, D., Kastner, L.Z., Buchner, T. et al. Sub-cycle atomic-scale forces coherently control a single-molecule switch. Nature 585, 58–62 (2020)

Possible usecases

from recent publications:
- Switching molecules
- Orbital imaging
- Vibrational excitation

planned in our group:
- polarisation dynamics of dielectric layers
- quantitative analysis of THz-induced voltage transients



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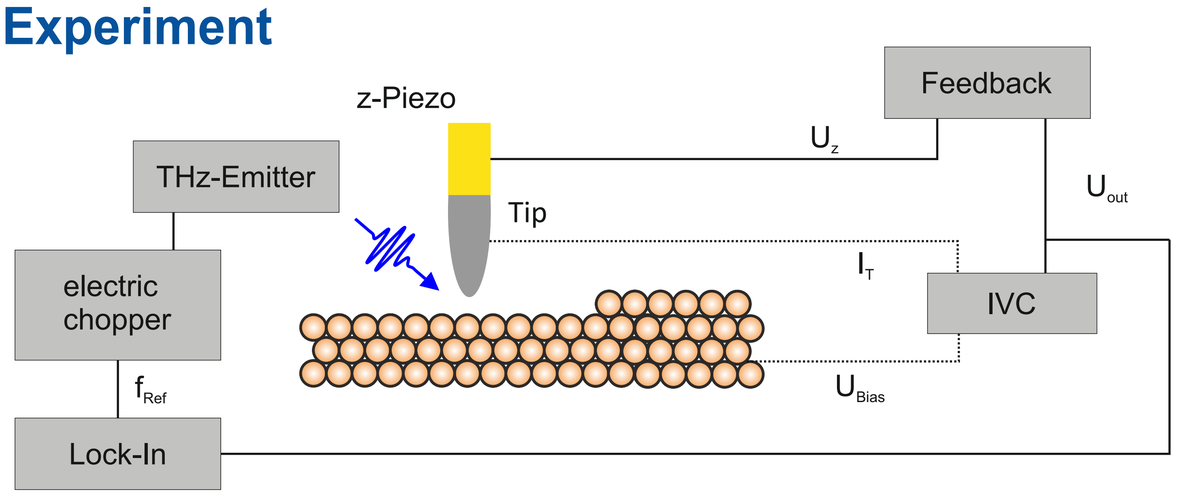
Experiment



THz measurements

- electric chopping of Thz
- Thz induces voltage transients across the junction
- Lock-In to detect THz-induced tunneling current

STM Measurements

- STM operates in constant-current mode
- feedback loop continously adjusts the height of the tip

Does the feedback see (and react) to the THz-chopping?

Boundary conditions for the chopping frequency:
- Lower limit: feedback should not be fast enough to react on the modulation
- Upper limit: Bandwidth of the IVC (decreasing gain at higher frequencies)

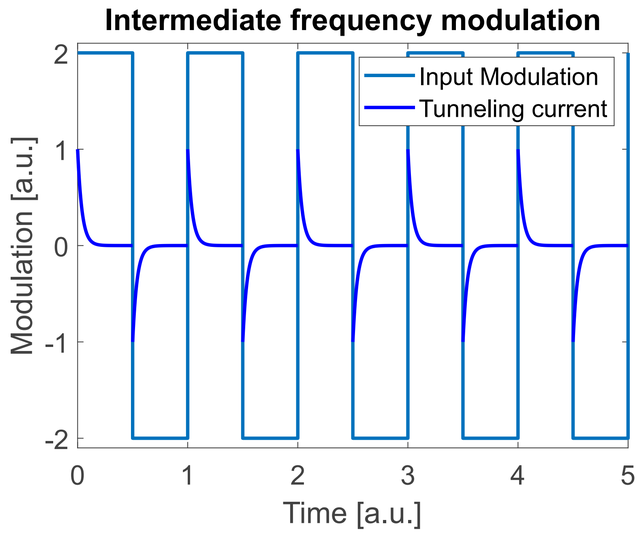
Popular commercial amplifier *Femto DLPCA-200* bandwidth:
- low noise: 1kHz
- high speed: 50kHz, but noise floor is too high!

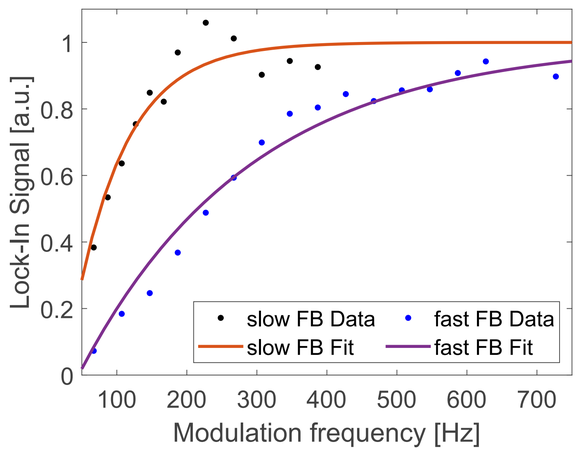
Results

Feedback loop

To test the feedback response:
- Modulate Z by using a square wave modulation
- Lock-In detection in tunneling current
- repeat for different modulation frequency

Borderline cases:
- Very slow feedback: square modulation of the tunneling current, feedback too slow to respond
- Very fast feedback: no modulation in tunneling current, feedback eliminates modulation





- Measurements for two feedback settings (“CI“ value in GxSM)
- The lock-in signal reaches saturation 300Hz and 750Hz respectively
- The influence of these feedback speed does not affect the >1000Hz chopping frequency

→ Neglegible influence on THz-STM

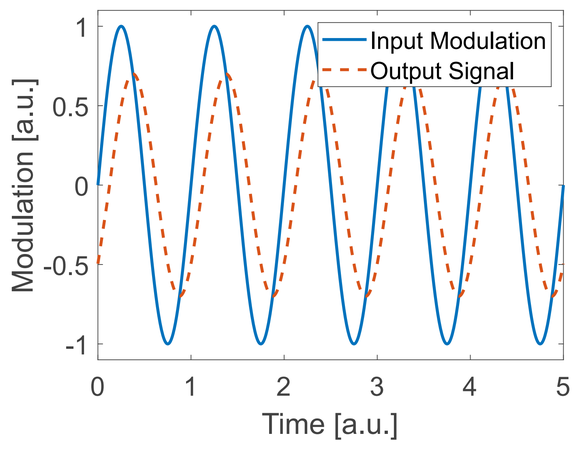
IVC (Current voltage converter)

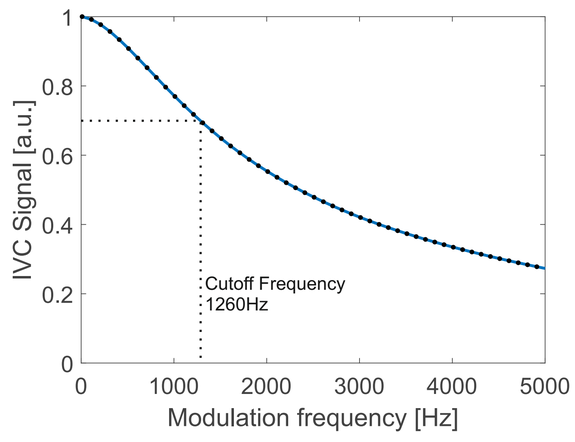
Problem:
- Gain decreases with modulation frequency
- Bandwidth of the current-voltage amplifier limits maximum chopping frequency

To test the bandwidth, a small modulation voltage is added to the bias voltage at the sample

- Cutoff frequency of our custom IVC is at 1260Hz

→ Chopping frequency of 1100Hz is adequate





Conclusion & Outlook

- A chopping frequency of approx. 1100Hz offers neglegible influence of the feedback while maintaining good signal strength
- THz-induced signal will be improved in the near future by the usage of next-generation THz-emitters replacing the current emitters

Funding

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DFG Deutsche Forschungsgemeinschaft

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References