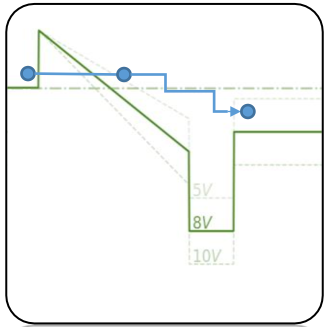
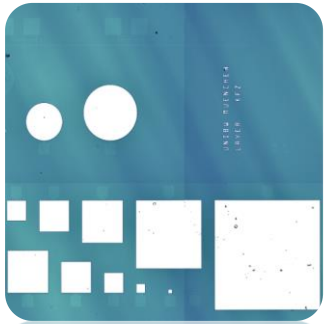
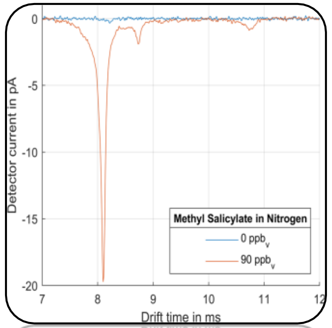
GOS







Pressure Insensitive Graphene-Oxide-Semiconductor Electron Field Emitter

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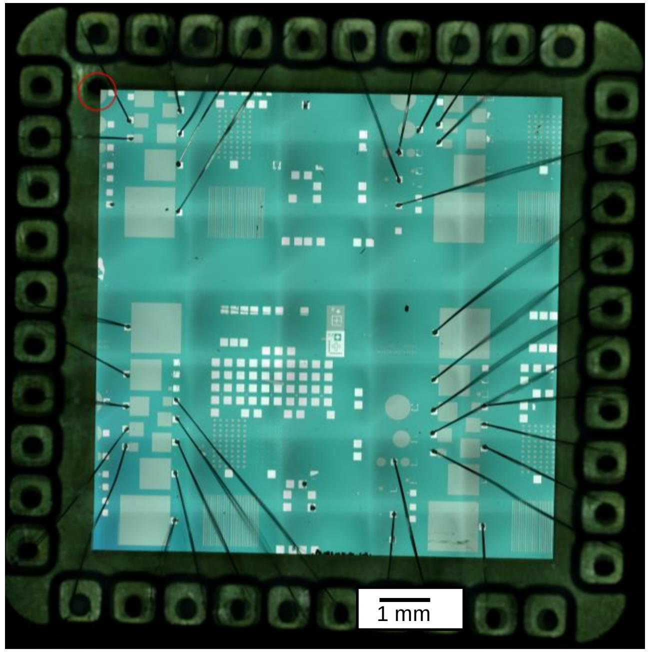
Motivation & Background

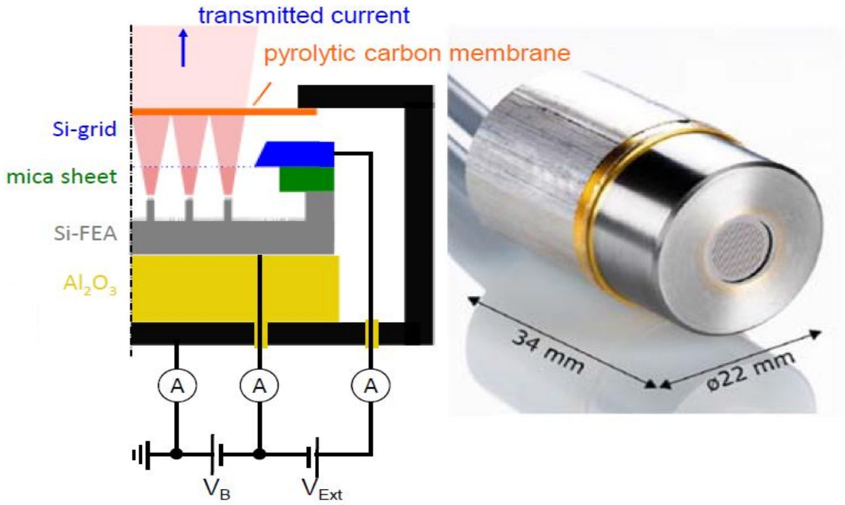
Goal → Electron emission into low vacuum and ambient pressure conditions

Applications Ion Source:
- Ion mobility spectrometry (IMS)
- Electron capture detector (ECD)
- Molecular filtering

Ambient pressure electron emitters
- Radioactive e.g. Ni63
- Encapsulated electron gun[1]

→ **MIS structures e.g. GOS**





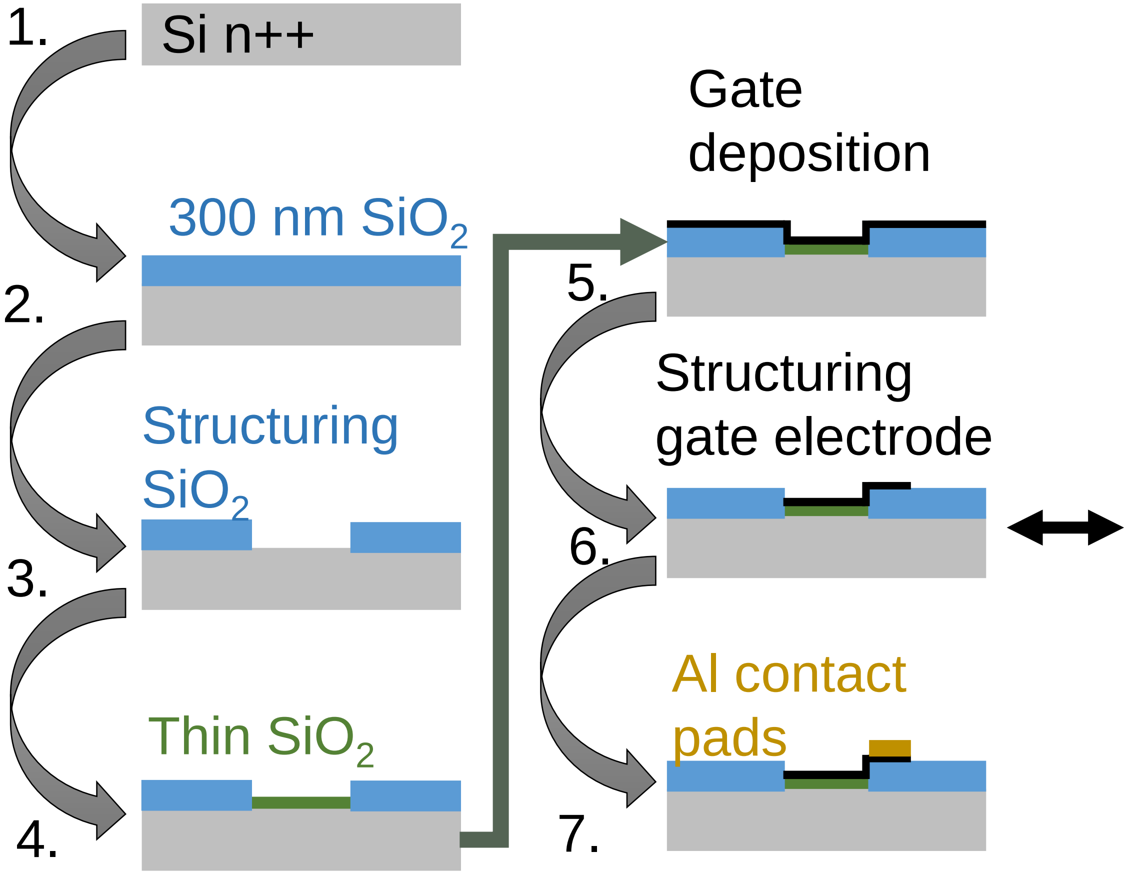
[1] M. Bachmann et al., (2020). *JVSTB*, *38*(2), 023203.

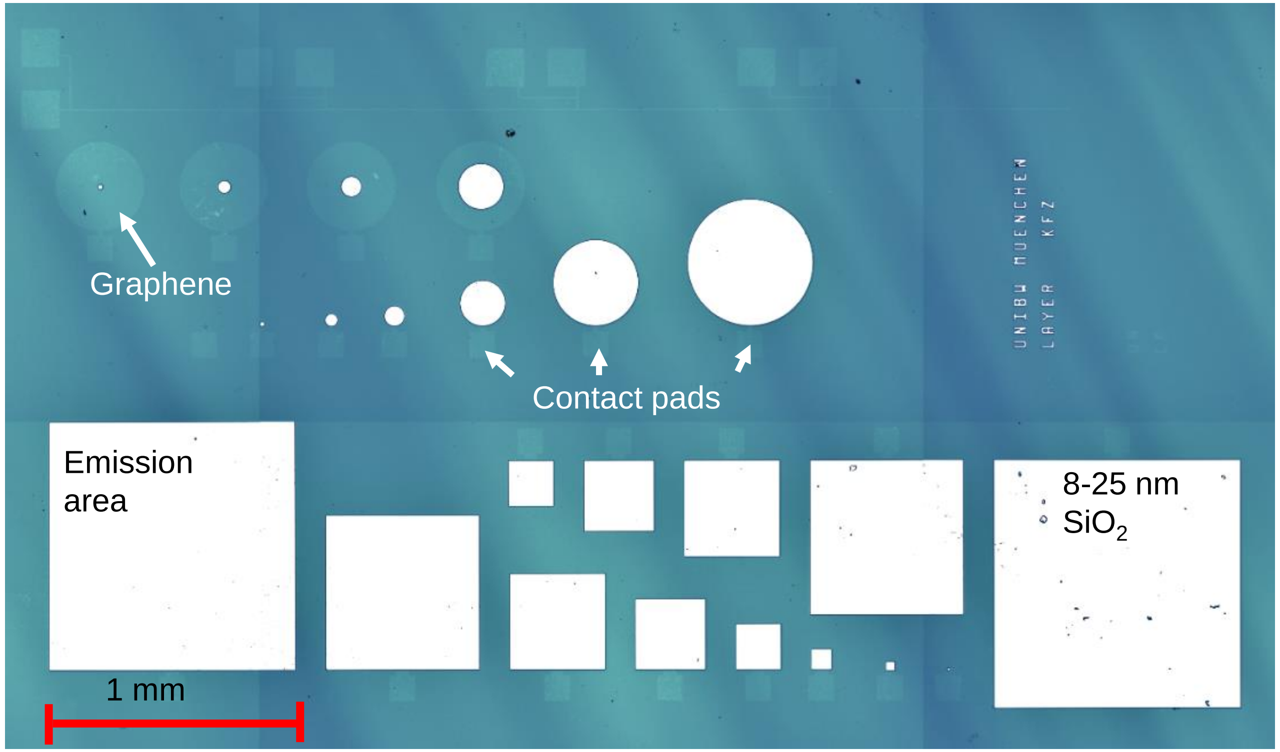
Advantages to other ion sources:
- Non-radioactive (compared to Ni63)
- Pulsable
- Small dimensions / low cost
- Low electron energies (< 50 eV)

Challenges:
- A high emission efficiency
- Sharp energy distribution of emitted electrons
- Low sheet resistance

Fabrication prozess

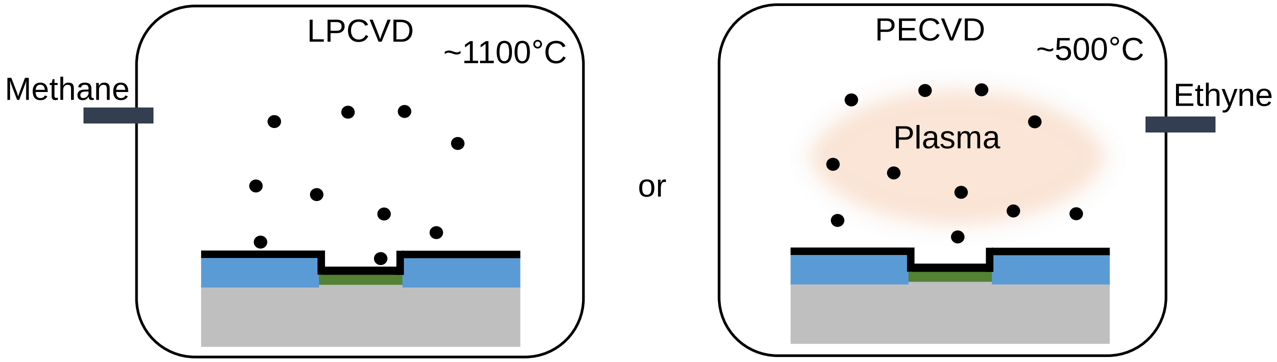
GOS





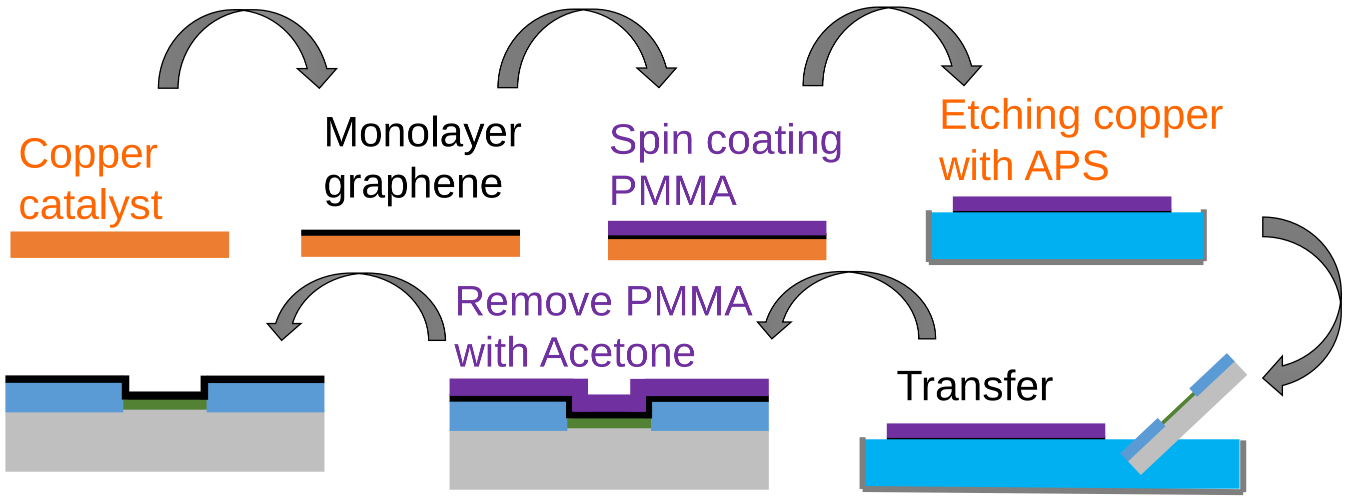
Gate electrode processes

Direct CVD on SiO_2:



R. Muñoz et al., (2018). *Nanoscale*, *26*.

Catalytically grown graphene (transfer):



LPCVD

- CH_4 decomposition at high temperature
- Methane as precursor
- Thickness in this study: 7.8±0.5 nm
- Poly crystalline graphenic carbon

PECVD

- C_2H_2 decomposition due to plasma
- Ethyne as precursor
- Thickness in this study: 11.2±0.5 nm
- Poly crystalline graphenic carbon

Transfer (catalytically grown)

- LPCVD grown on Copper
- Thickness: Monolayer (~0.32 nm)
- Wrinkles and cracks are possible

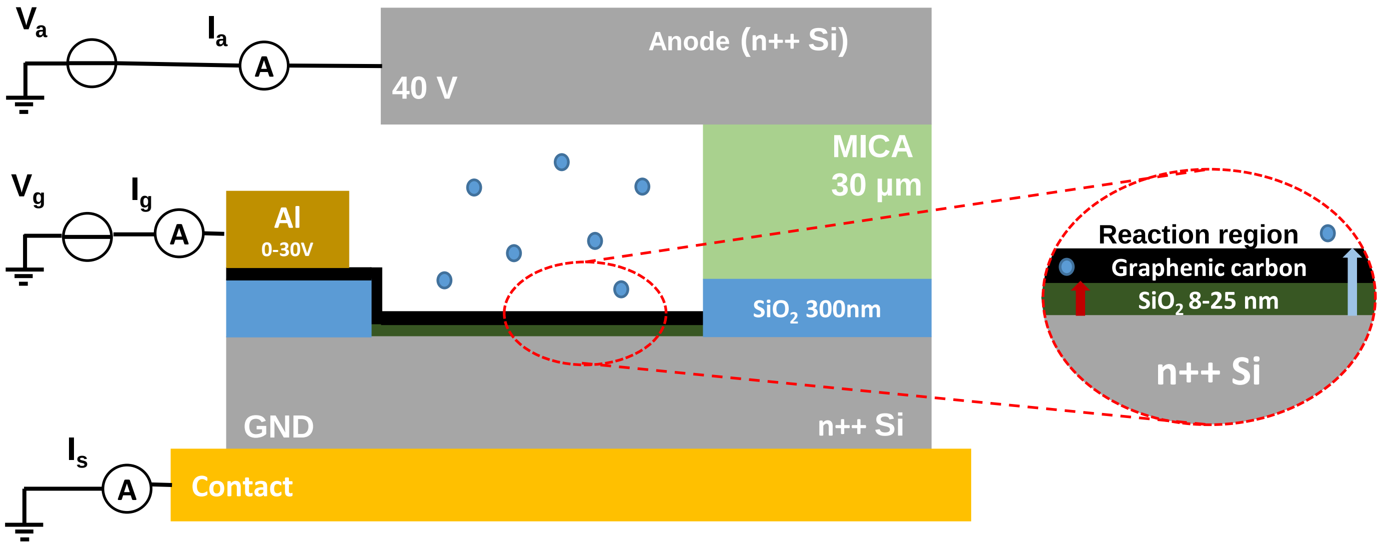
Measurement setup

Vacuum setup

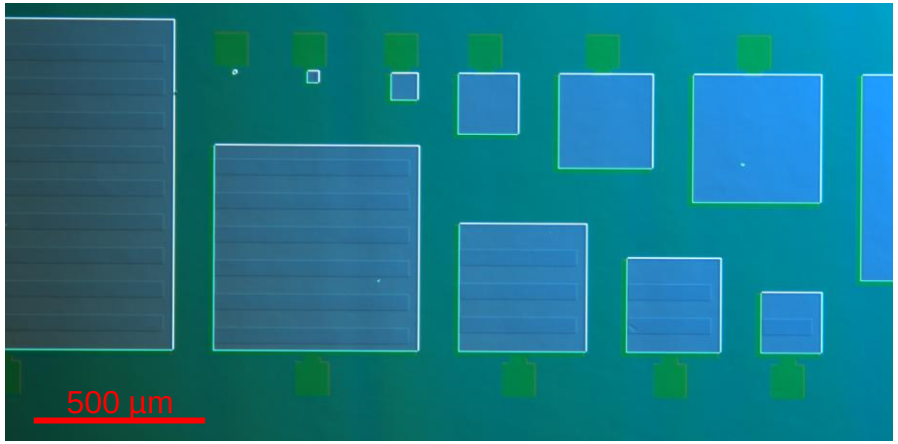
- Characterization at 10^{-3} mbar
- 99% pure nitrogen source for ambient pressure measurements
- Highly n-doped Si anode @ 30µm

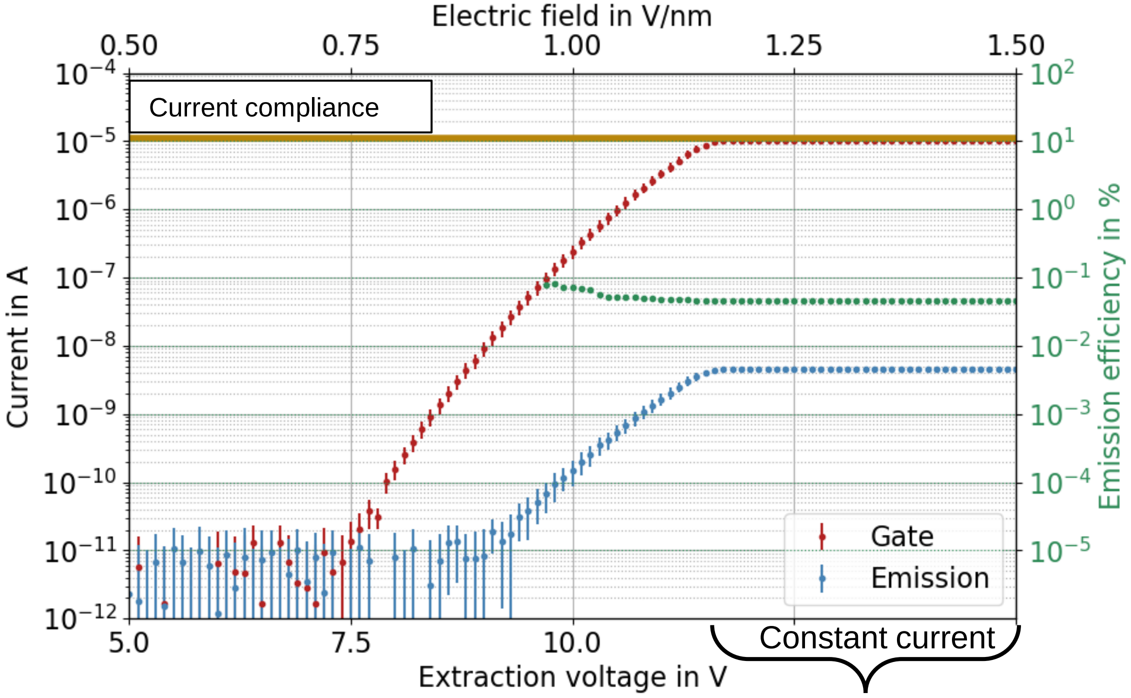
Electrical measurement

- Gate (extraction) voltage is swept up to 30 V
- Current compliance of 10 µA at the gate electrode
- Anode voltage is held constant at 40 V
- Anode current is associated with the emitted current



LPCVD grown graphenic carbon





GOS Sample - LPCVD

- 10 nm tunnel oxide
- Emission area of (300x300)µm^2
- Thickness graphenic carbon: 7 nm

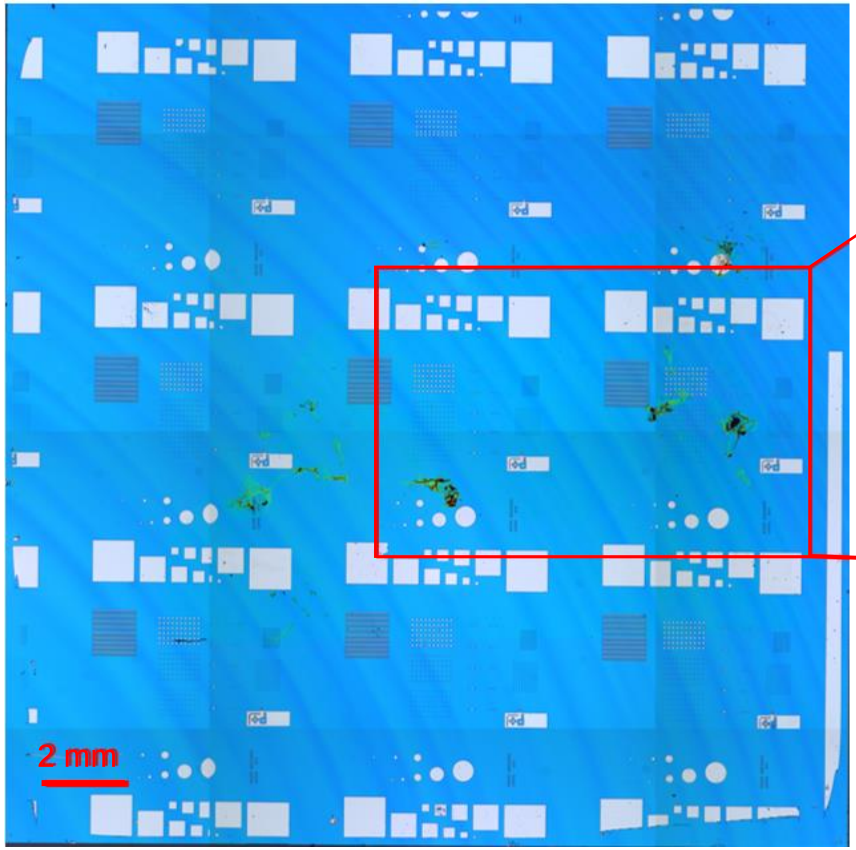
Electrical characterization

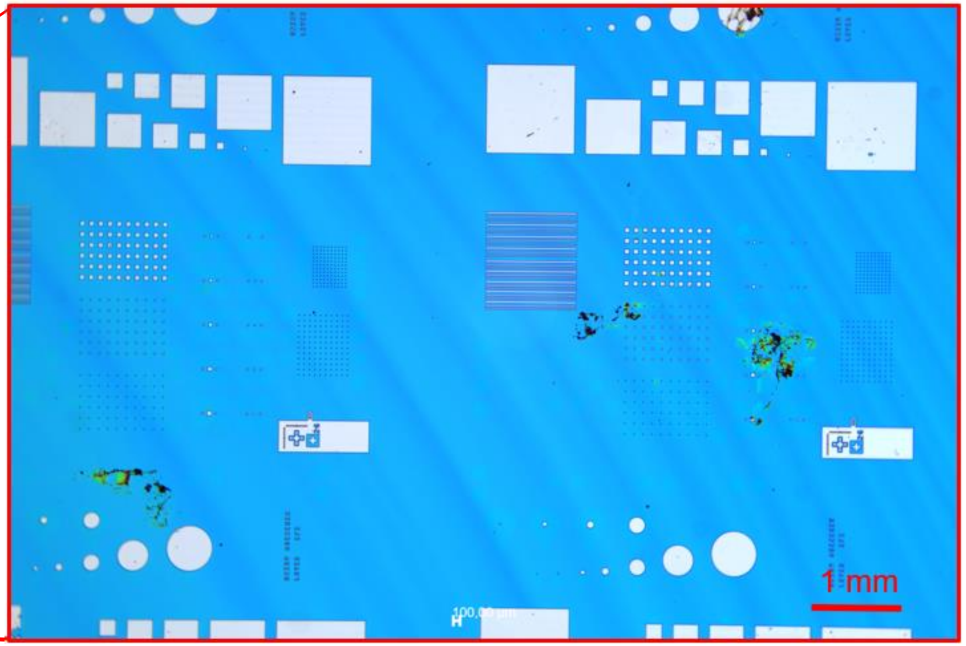
- 6 averaged sweeps
- Gate current compliance at 10µA
- Highly stable characteristics
- Emission efficiency up to 0.1%
- Currents up to 5nA

Transferred monolayer graphene

After structuring

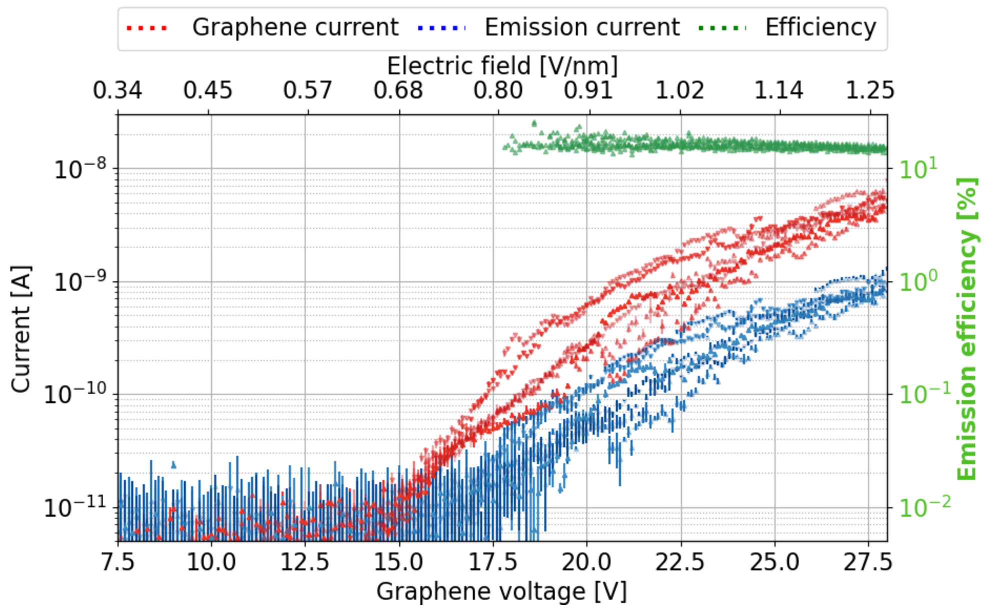
Before structuring

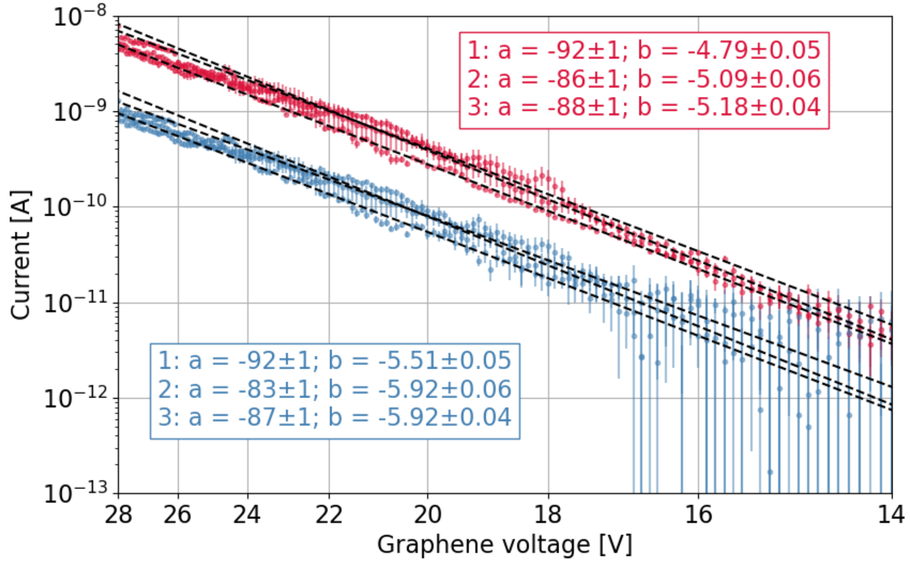




- Transfer process introduces **wrinkles & holes**
- PMMA at the wrinkles stays after structuring with O2 Plasma
- Structuring the Al-pads with PNA also introduces holes in the sheet → Lift-off process
- Transferred process is elaborate
- The yield of transferred graphene samples is diminished

Transferred monolayer graphene





GOS Sample – Transfer

- 22 nm tunnel oxide
- Emission area of (300x300)μm^2
- Three up and down sweeps
- Hysteresis → filling and emptying of traps
- Emission efficiency up to 23%
- Surpasses efficiency of former monolayer GOS by factor of 2[1]
- Currents up to 1nA

Millikan-Lauritsen representation

- Nearly linear behavior → Fowler-Nordheim tunneling
- Emission and gate slopes are congruent

[1] M. P. Kirley et al., (2017), *Appl. Phys. Lett.*, *110*(23).

Emission efficiency

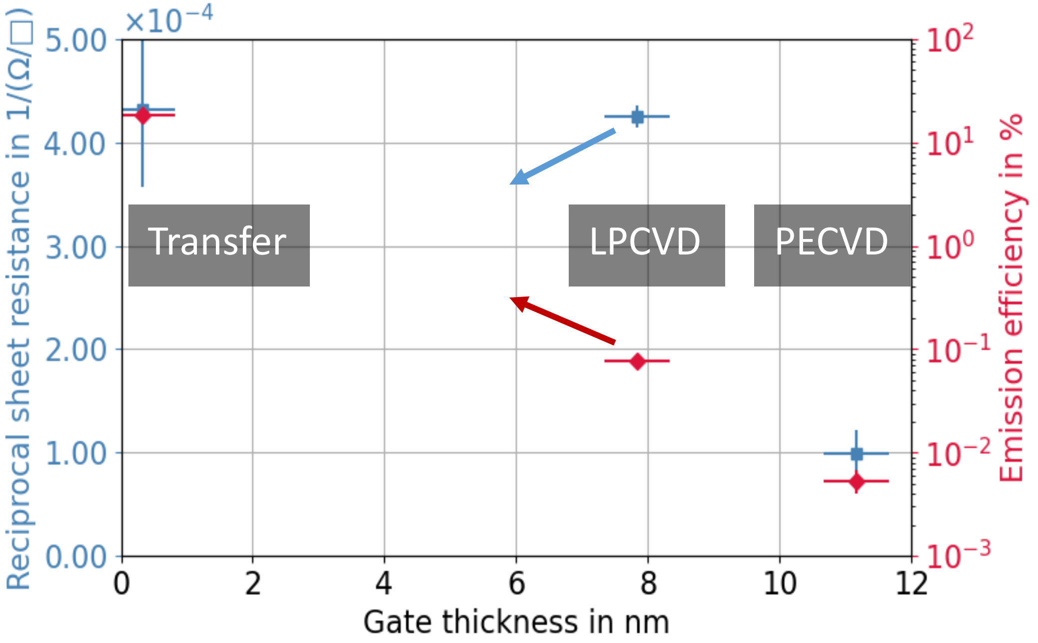
- Presumably depends on gate thickness
- Monolayer graphene has the highest value
- Thinner carbon <-> emission efficiency is expected to increase

Sheet resistance

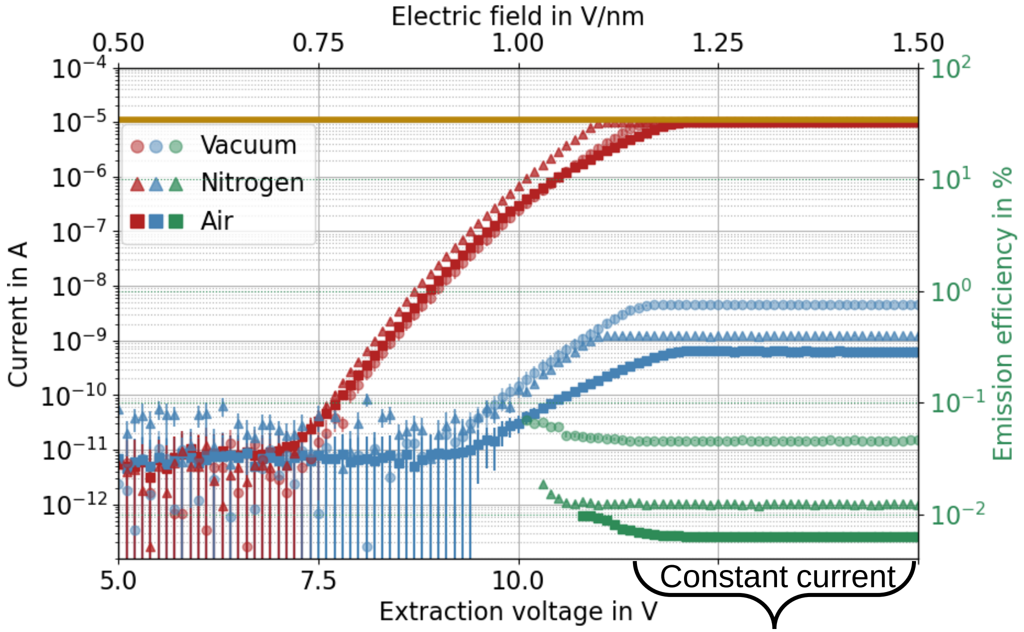
- Transfer graphene has the lowest sheet resistance
- Thinner carbon <-> sheet resistance is expected to decrease

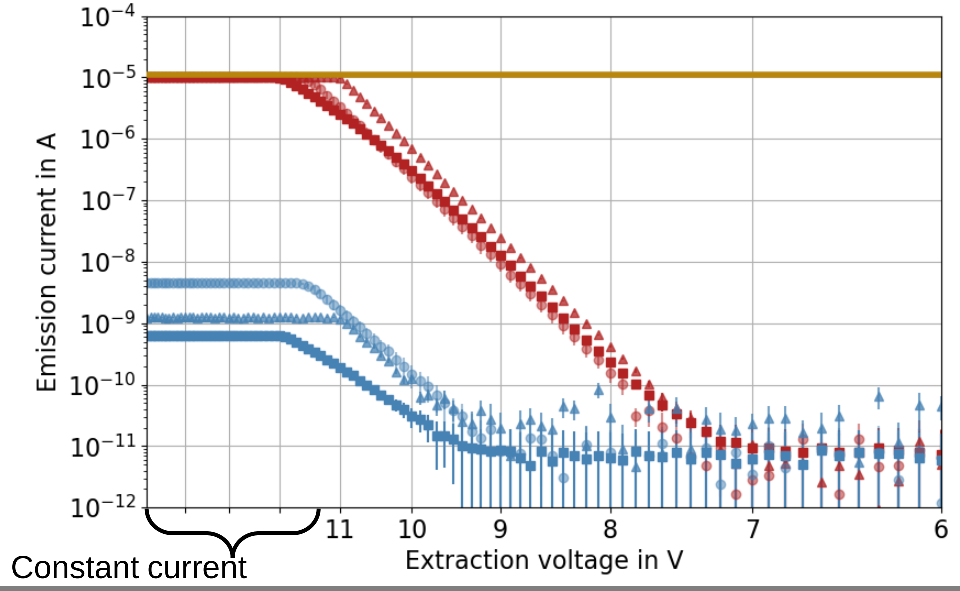
Gate thickness

- Homogeneous monolayer CVD graphene is difficult to achieve
- Transfer graphene is laborious and causes wrinkles and cracks



Performance at atmospheric pressure





Characteristics

- Average of minimum 6 sweeps
- Three different samples/chips of **LPCVD** graphene
- Tunnel current dose not depend on pressure or gas
- Nitrogen/Air at 970 hPa (mean pressure in Munich)
- **Stable emission into atmospheric pressure conditions**

Millikan-Lauritsen representation

- All three are nearly linear
- Fowler-Nordheim tunneling is expected to be the conduction mechanism

Conclusion and outlook

Conclusion

- Investigation of 3 different graphemic carbon gates
- Monolayer graphene has the highest emission efficiency and lowest sheet resistance
- Emission is stable and reproduceable over several batches
- Emission can be conducted at atmospheric pressure conditions of nitrogen and air

Outlook

- Lower thicknesses of the CVD graphenic carbon (GC)
- PECVD GC → investigation on the lifetime
- Lifetime measurements at atmospheric pressure conditions
- Investigation on the dependency of the oxide thickness
- Analysis of the energy distribution of the electrons
- Hexagonal boron nitride as the insulator → sharper distribution
- Ionization of different species

Acknowledgement

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- Dr. Andreas Pahlke