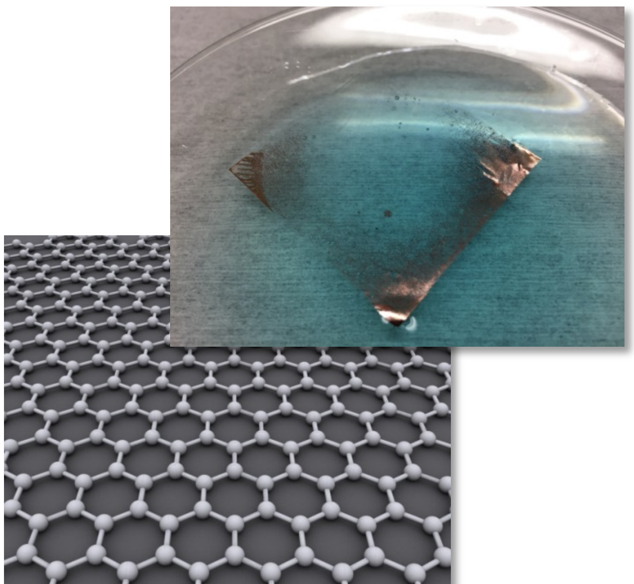
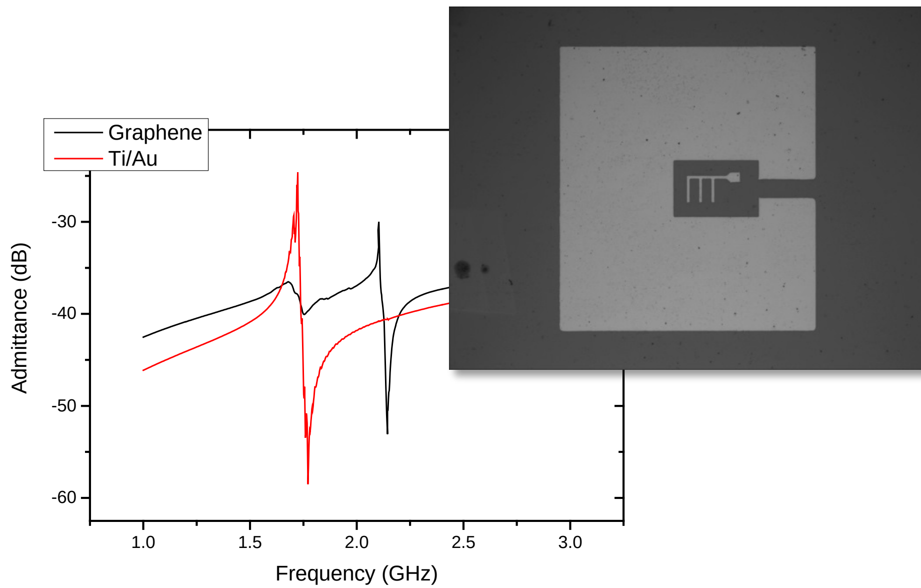
GRAPHENE AS VIRTUALLY MASSLESS TOP ELECTRODE FOR RF BULK ACOUSTIC WAVE (BAW) RESONATORS

Marius Knapp[1], V. Cimalla[1], D. Schwantuschke[1], V. Lebedev[1], O. Ambacher[2], R. Hoffmann[1]





[1] Fraunhofer Institute for Applied Solid State Physics IAF, Tullastraße 72, 79106 Freiburg, Germany

[2] Department of Microsystems Engineering– IMTEK, University of Freiburg, Germany

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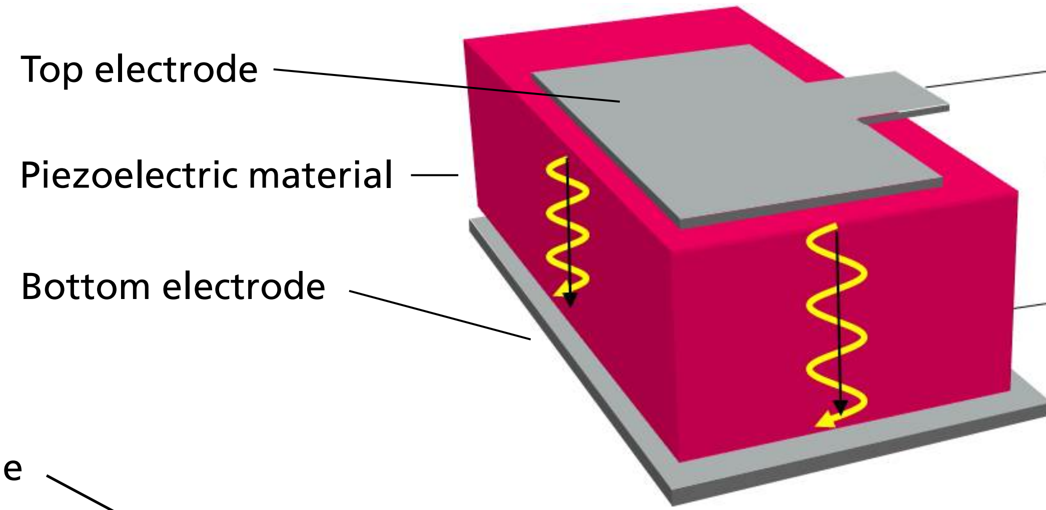
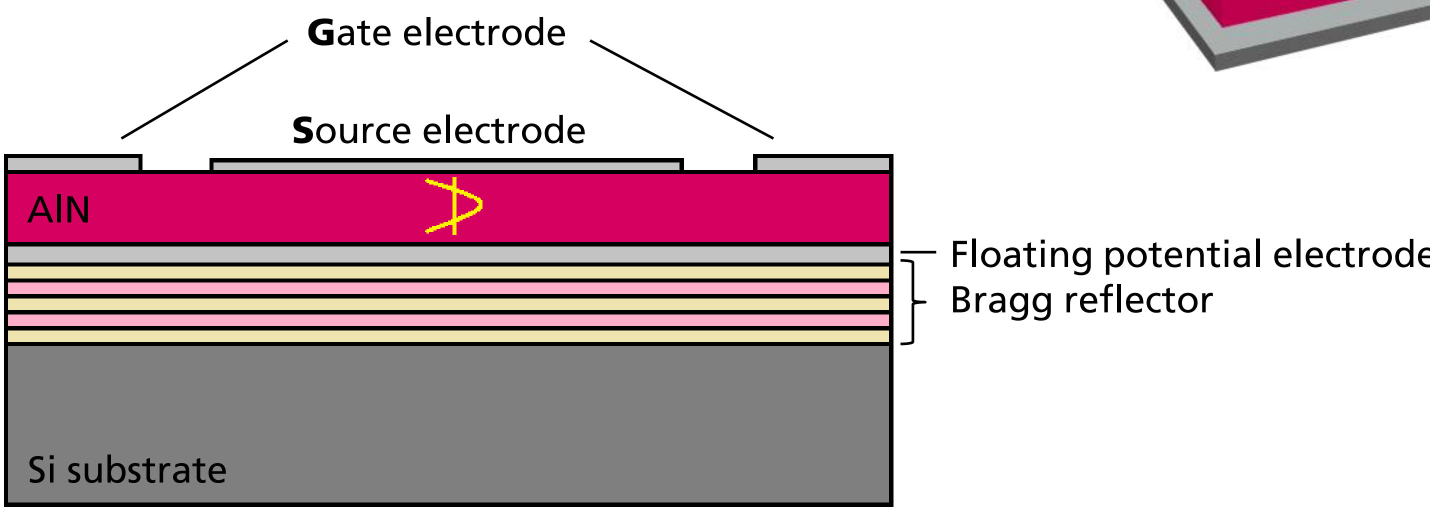
Motivation

- BAW resonators are key-building blocks for radio frequency (RF) filters used in wireless communication devices (e.g. smartphones)

Source: Oleksiy mark - Fotolia

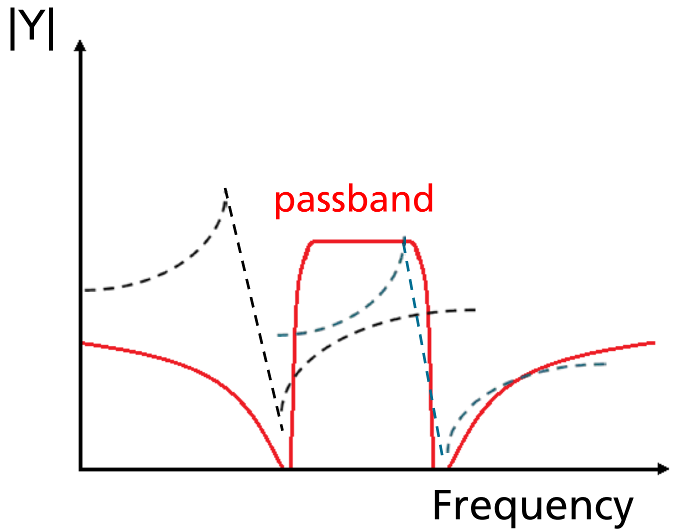
Bulk acoustic wave (BAW) resonator

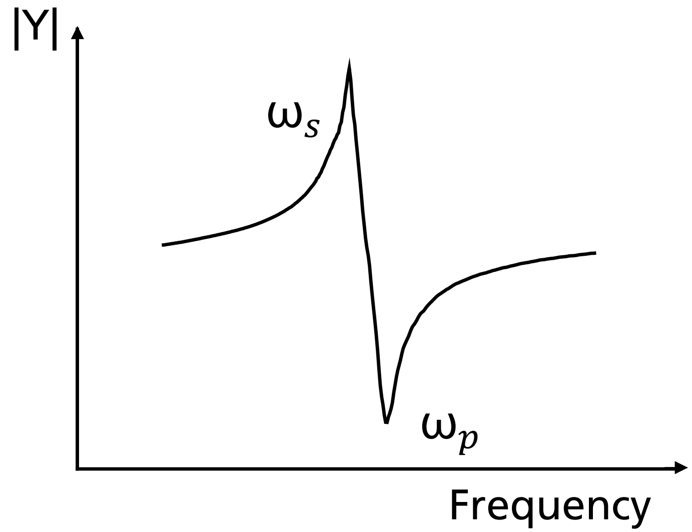


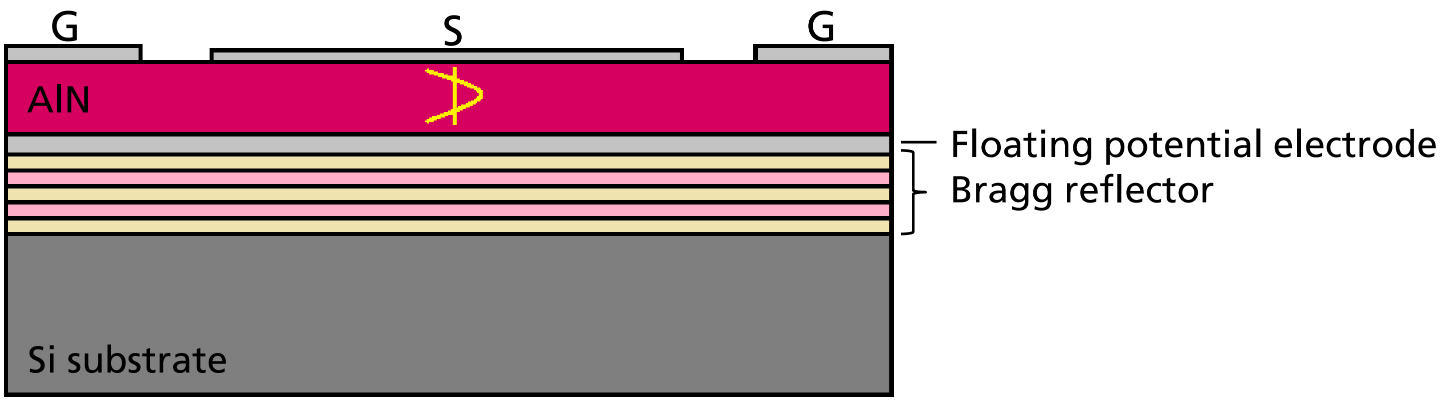


Solidly mounted resonator (SMR)

Bulk acoustic wave (BAW) resonator







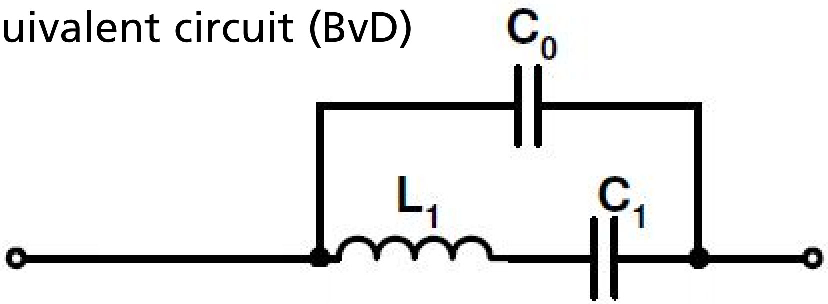
BAW-SMR

Bulk acoustic wave (BAW) resonator

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}}$$

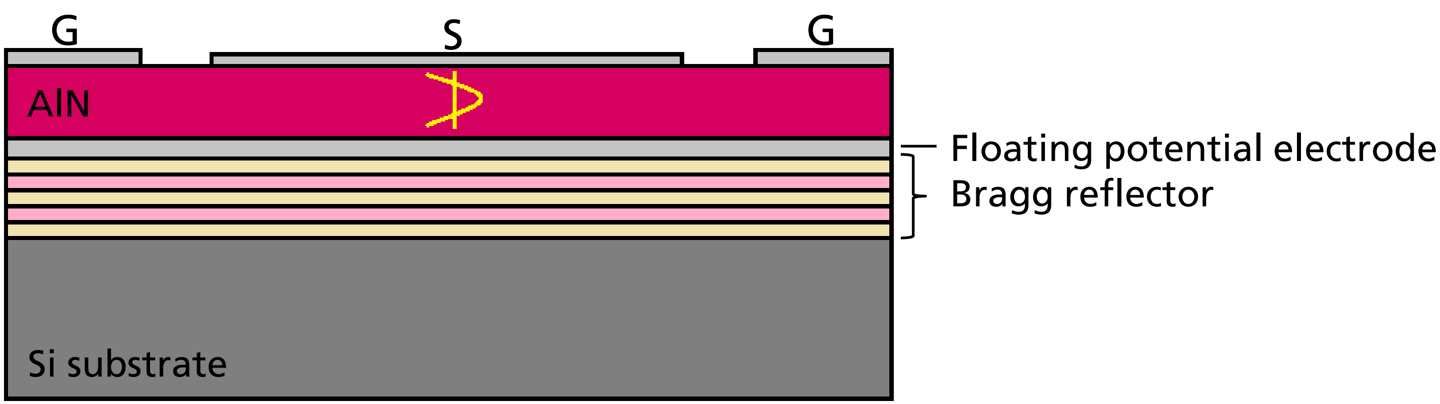
$$\omega_p = \frac{1}{\sqrt{L_1 C_1}} \sqrt{1 + \frac{C_1}{C_0}}$$

Equivalent circuit (BvD)



C_0: total plate capacitance

L_1, C_1: mechanical resonator branch

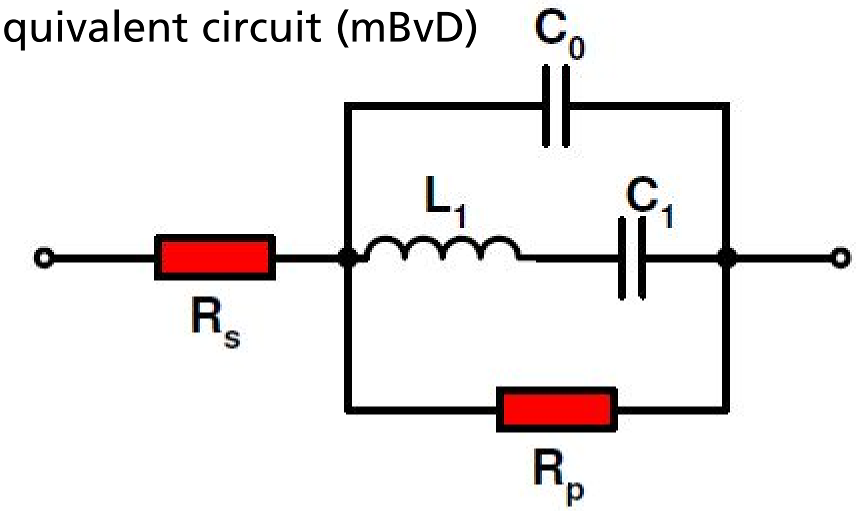


BAW-SMR

Electrode induced electrical and mechanical losses in BAW resonators

- Parallel resistor R_p represents viscous and dielectric losses **(non-zero electrode mass)**
- Serial resistor R_s represents ohmic losses **(non-zero electrode resistance)**

Equivalent circuit (mBvD)



Q factor as main resonator characteristic

$$Q_s = \frac{1}{R_s}\sqrt{\frac{L_1}{C_1}}$$

$$Q_p = \omega_p R_p \frac{C_1 + C_0}{C_1} C_0$$

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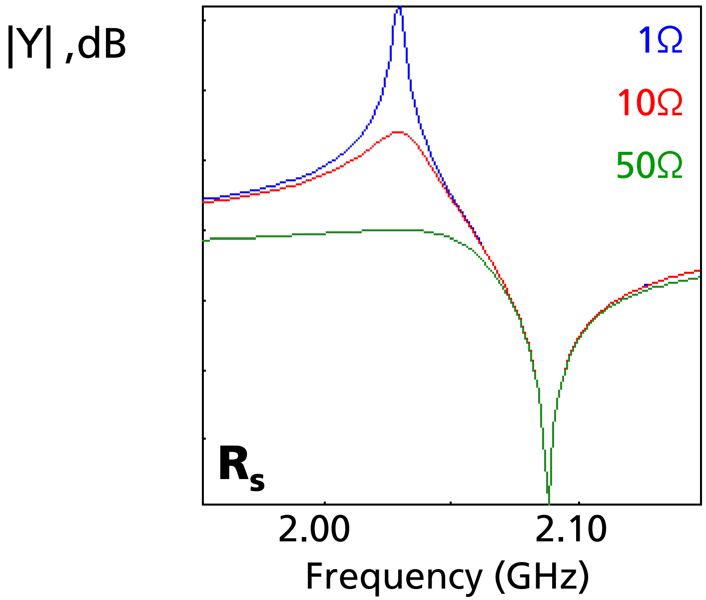
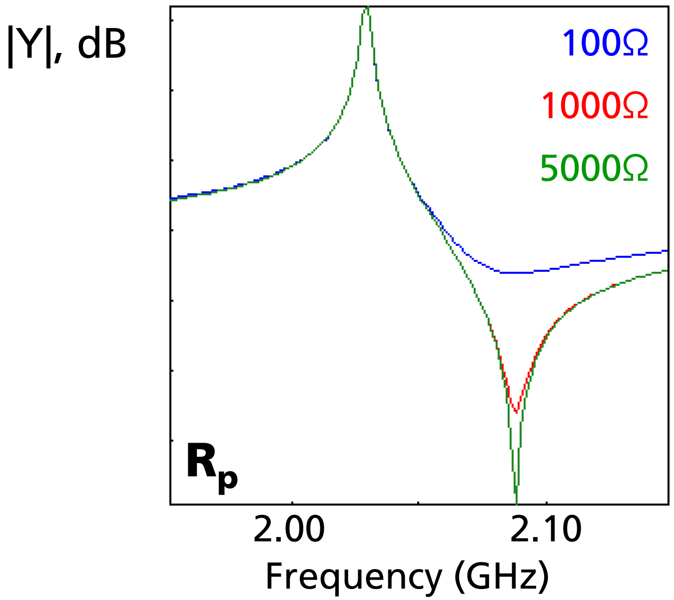
Influence of R_s and R_p on admittance curves





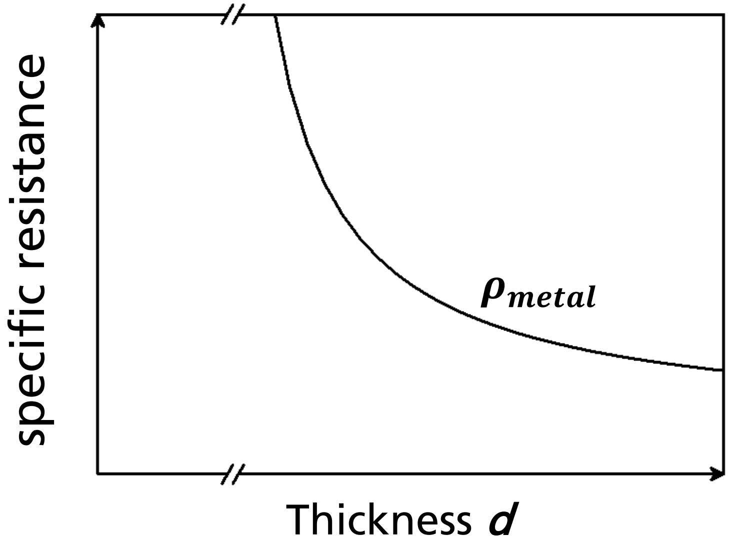
- Resonance peak sharpness indicates Q factor
- Q strongly depends on losses

Idea: thin conductive electrodes to reduce viscous losses

Graphene as massless electrode – Fuchs-Sondheimer model

- Fuchs-Sondheimer model

$$\rho_{ges} = \rho_{bulk} + \rho_{SS},\ \rho_{SS} \sim \left(1 + \frac{1}{d * ln\frac{1}{d}}\right) * \rho_{bulk}$$



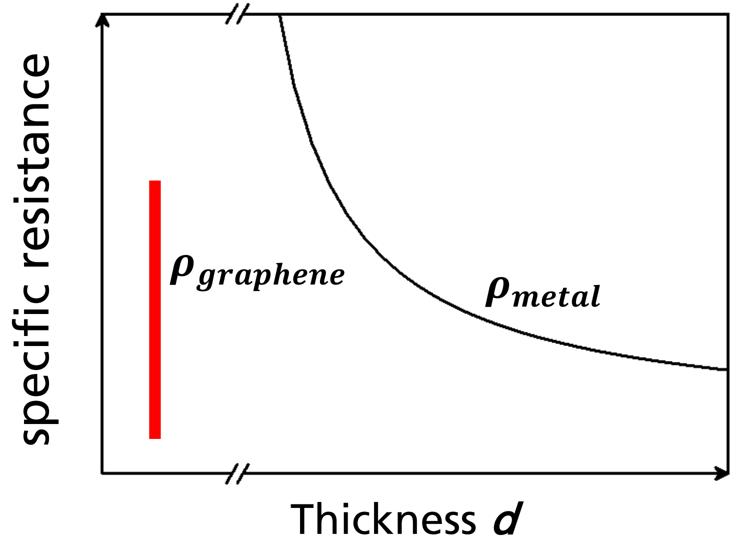
Graphene as massless electrode – Fuchs-Sondheimer model

- Fuchs-Sondheimer model

$$\rho_{ges} = \rho_{bulk} + \rho_{SS}, \ \rho_{SS} \sim \left(1 + \frac{1}{d * \ln\frac{1}{d}}\right) * \rho_{bulk}$$

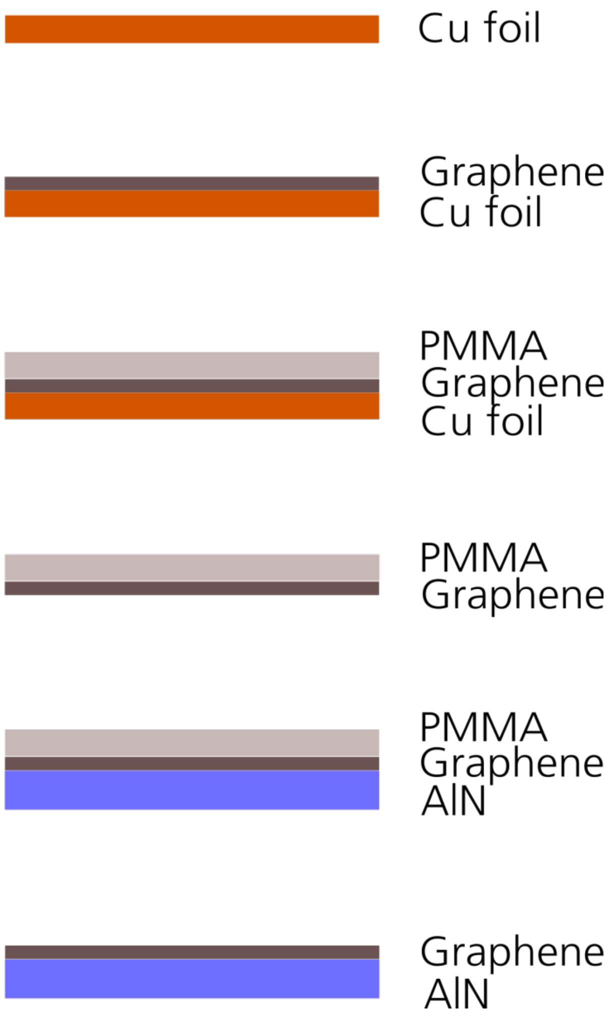
- Graphene is virtually massless , still conductive

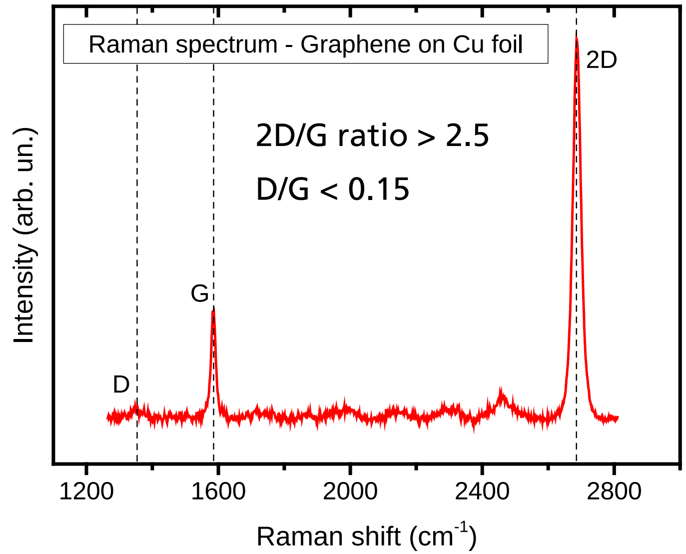
➡ **Reduction of viscous losses!**



Replacement of conventional metal electrodes (Ti/Au) with graphene

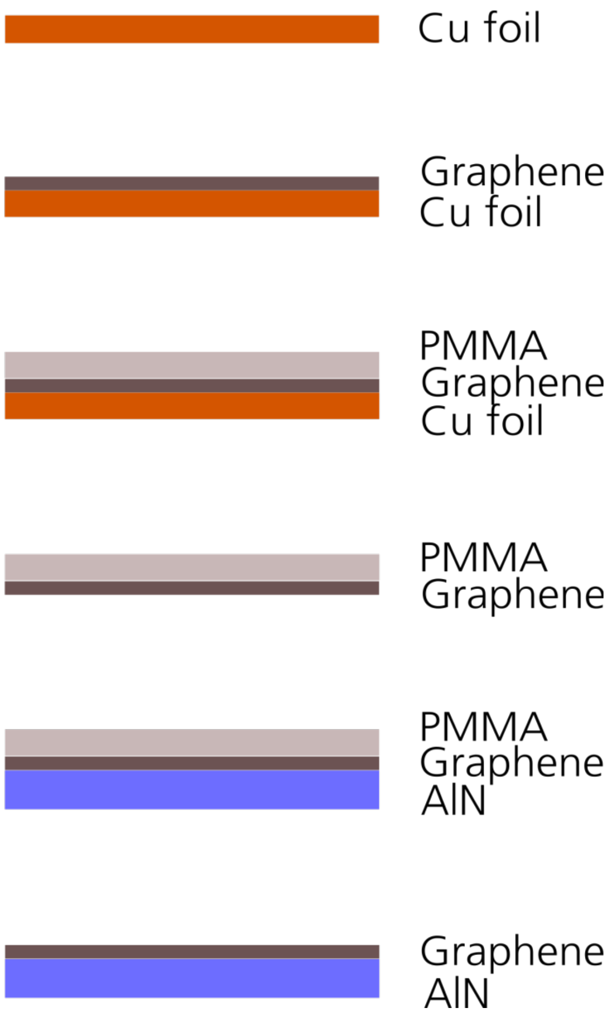
Process development – Graphene growth and transfer

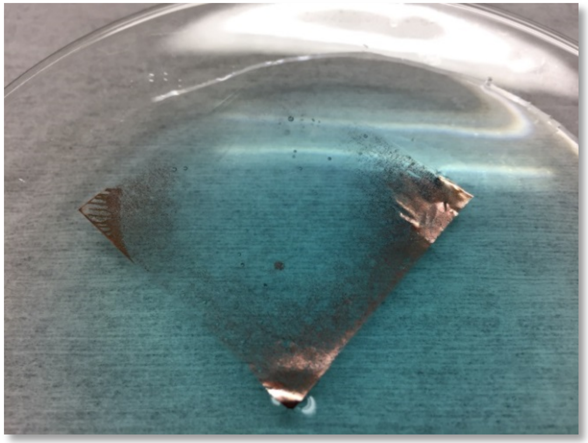




- Standard CVD process
  - Aixtron BlackMagic CVD reactor
  - Methane as precursor, H_2 as carrier gas
  - Cu foil as catalytic substrate

Process development – Graphene growth and transfer





Cufoil etching in APS

- Graphene wet transfer process
  - Poly (methyl methacrylate) (PMMA) as protecion layer
  - Cu foil etching in Ammonium persulfate (APS)

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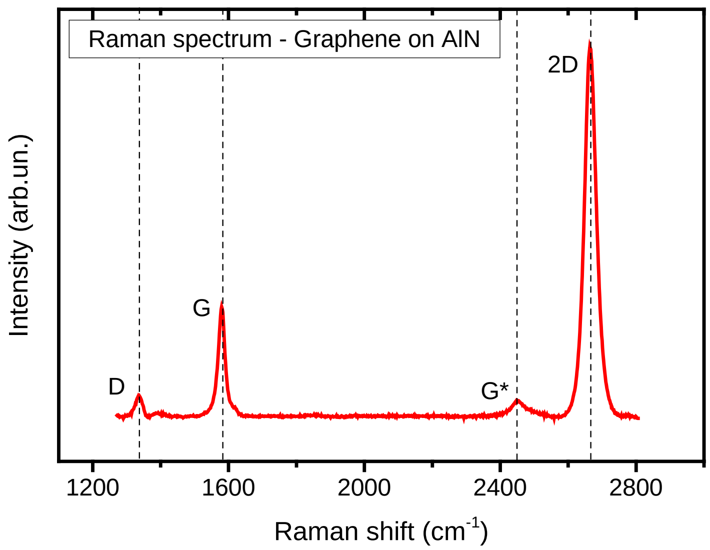
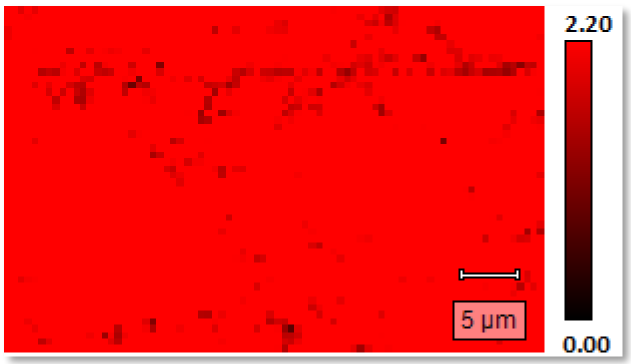
Process development – Graphene growth and transfer



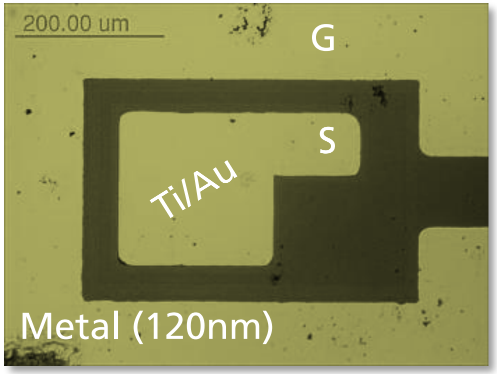


Raman spectrum - area scan

- Sheet resistance of graphene on AlN via 4-point-measurement:

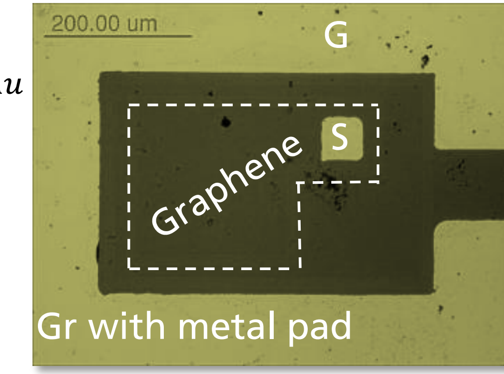
40 x 40 mm²	Reproducable R_S < 2kΩ
40 x 40 mm²	Best $R_S \approx 350\Omega$
15 x 10 mm²	Best $R_S \approx 280\Omega$

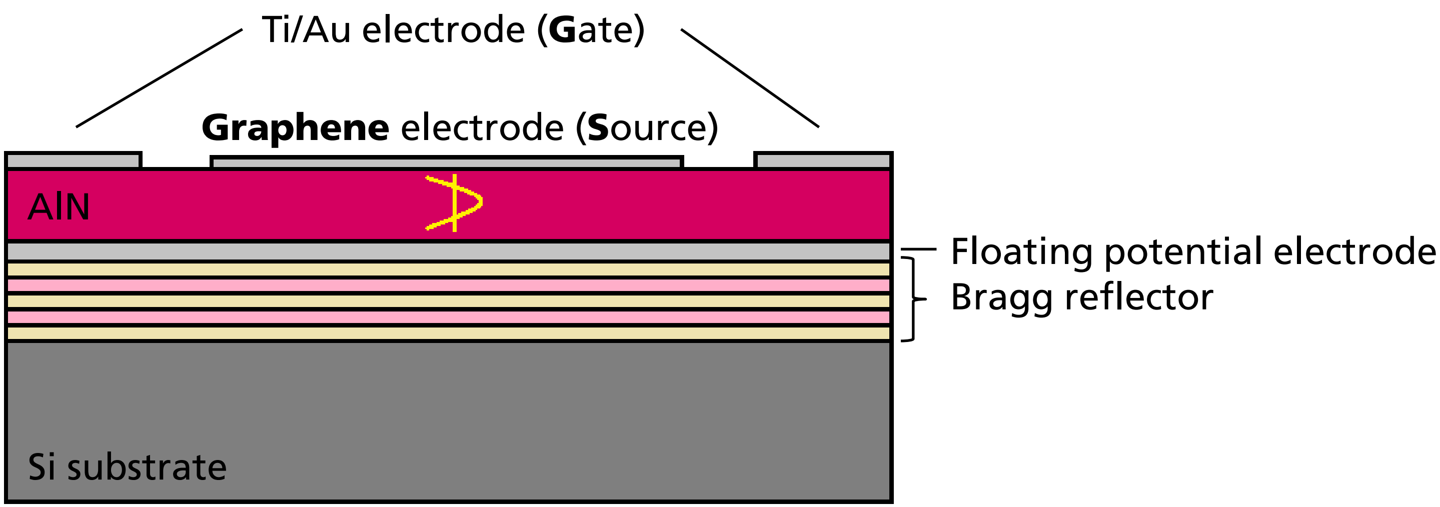
BAW-SMR device design



Mass reduction:
$m_{Gr} = 0.00037\, m_{Ti/Au}$

resonator area:
200x200µm²





BAW-SMR

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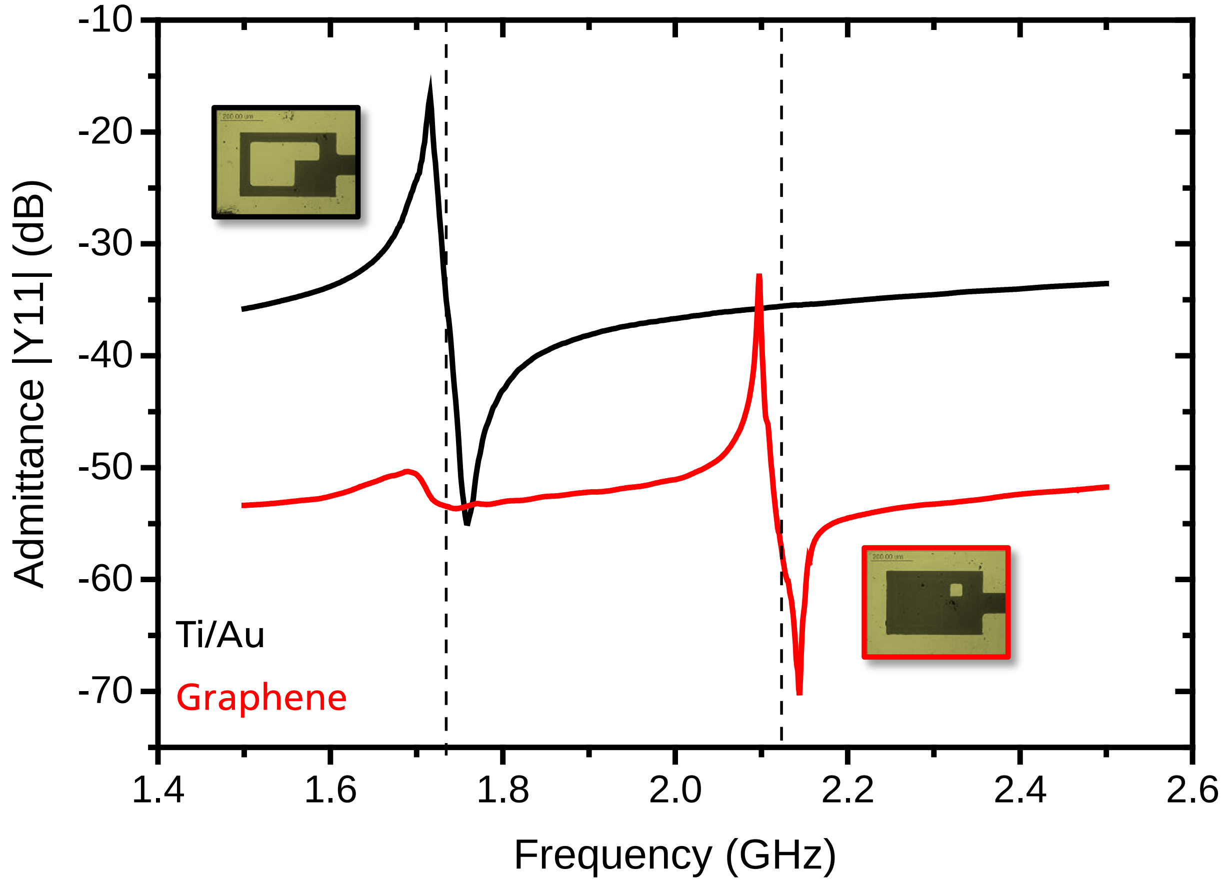
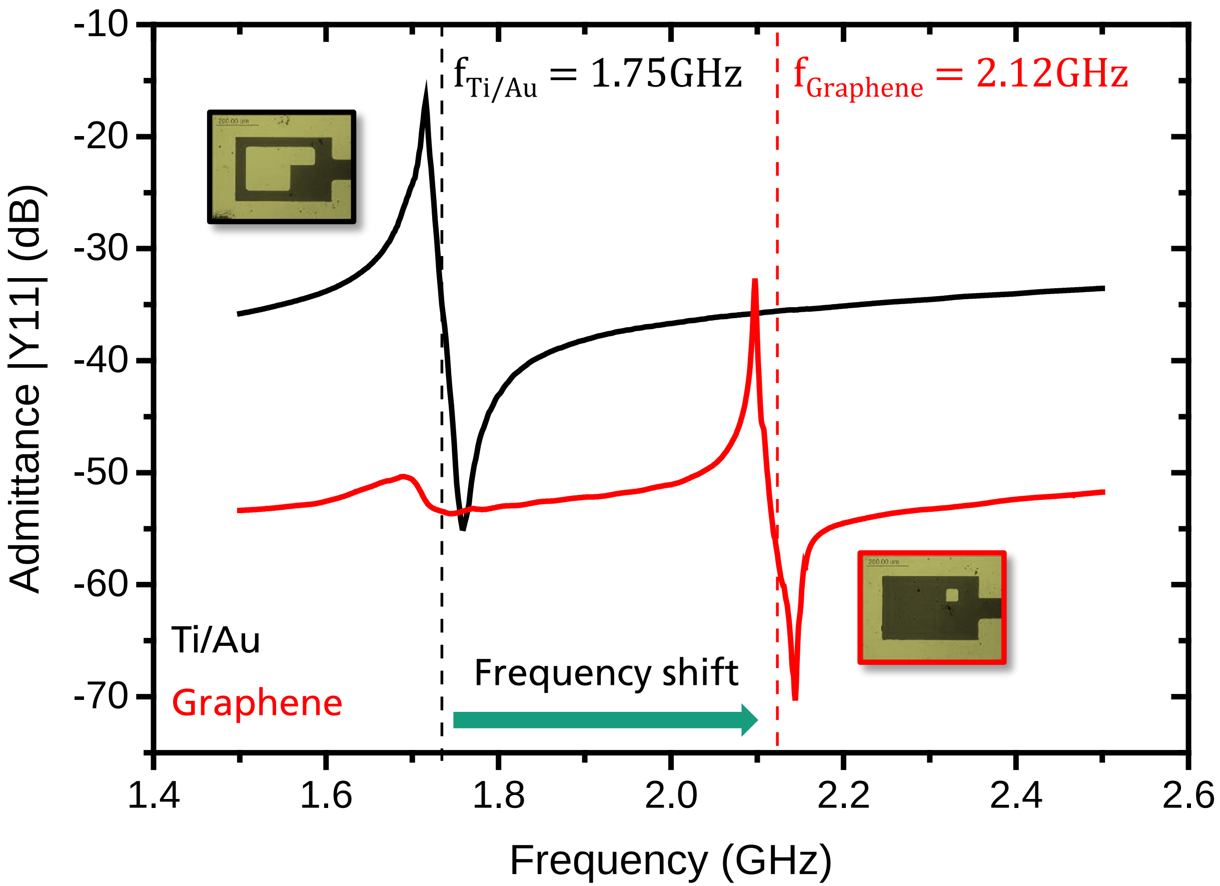
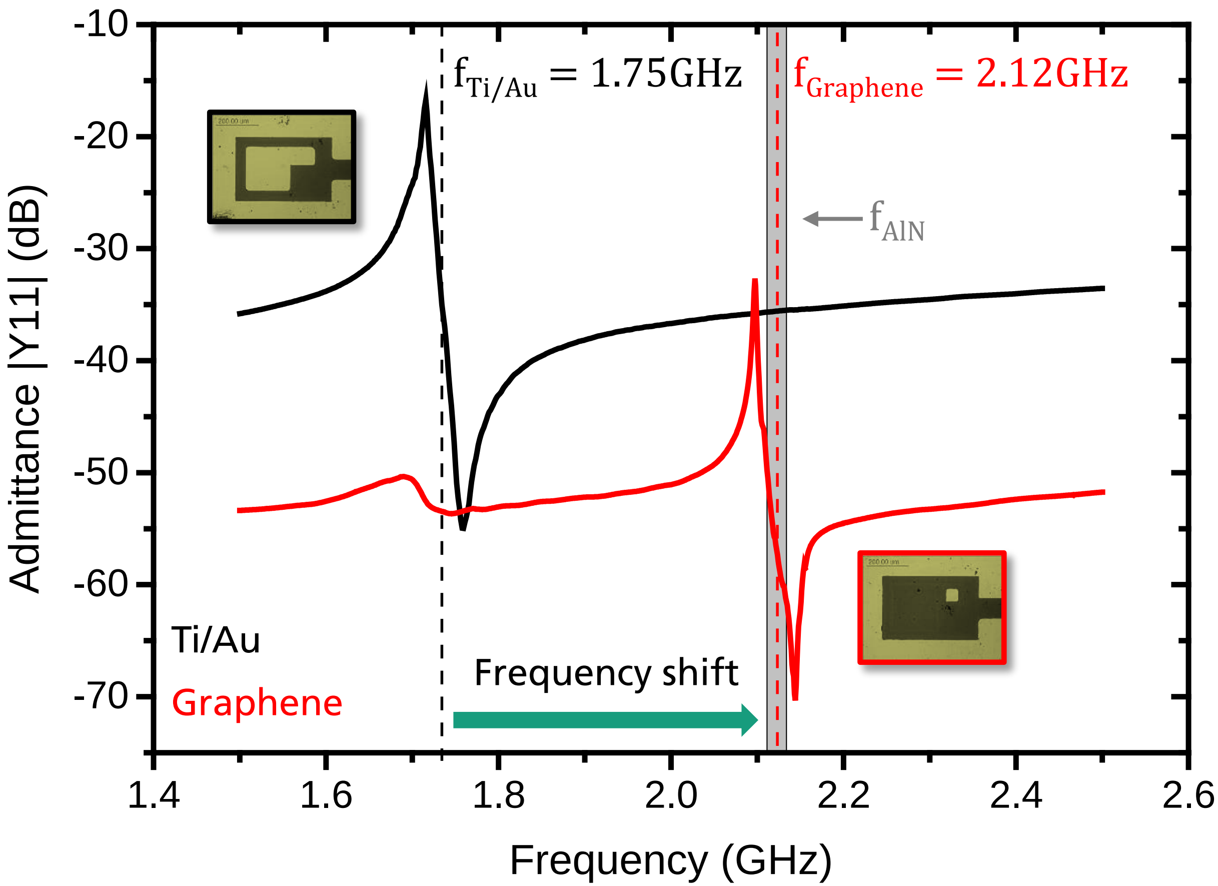
Electrical characterization – network analyser measurements



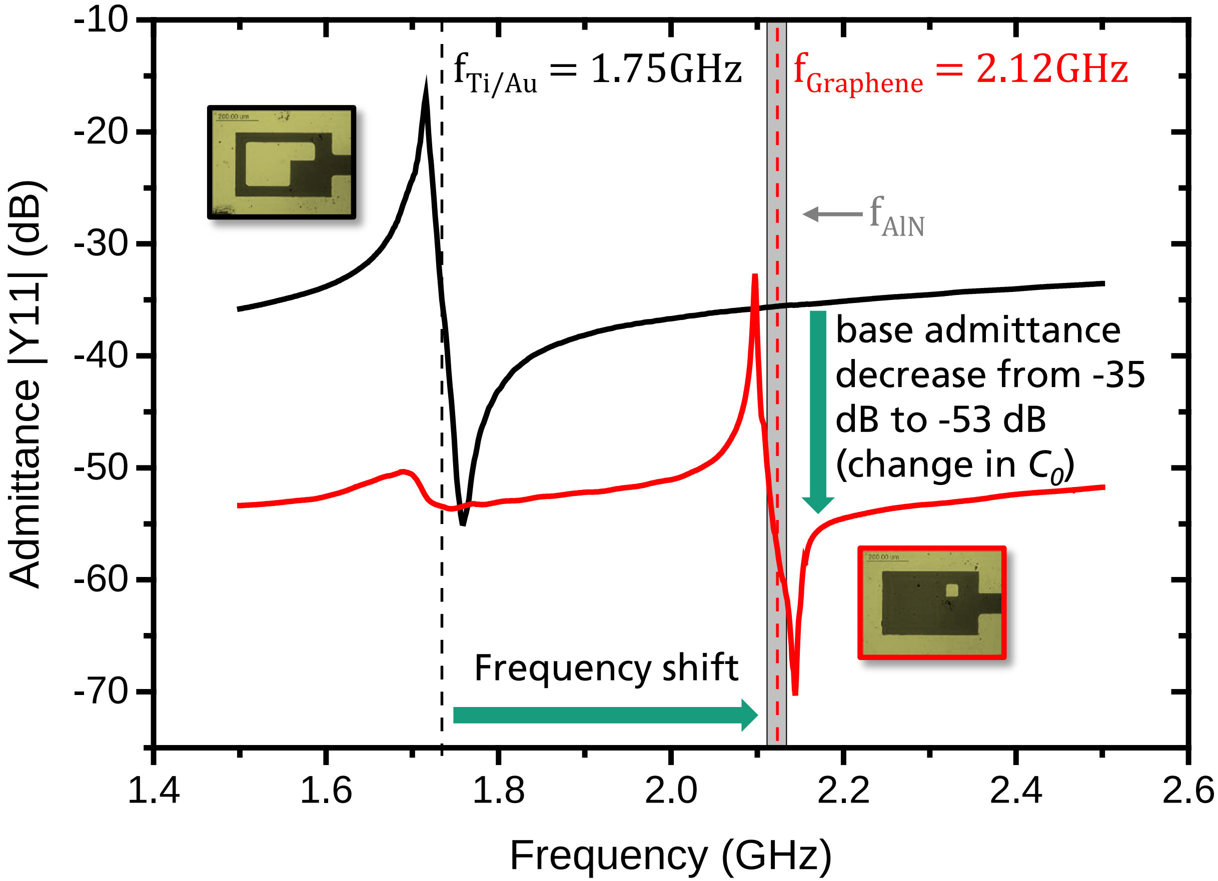
Electrical characterization – network analyser measurements



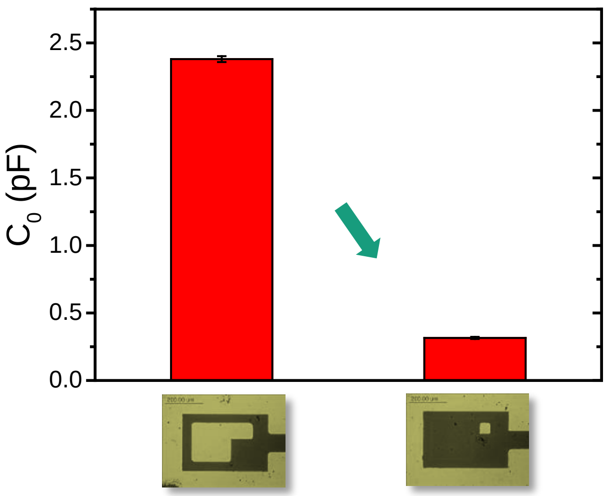
Electrical characterization – network analyser measurements

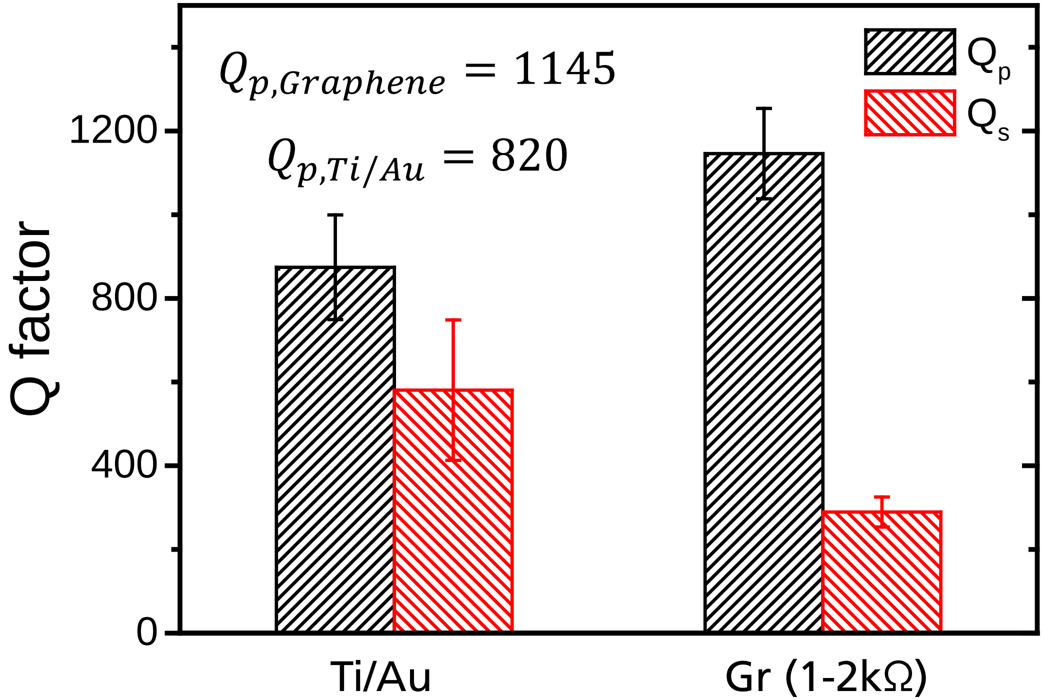


Electrical characterization – network analyser measurements



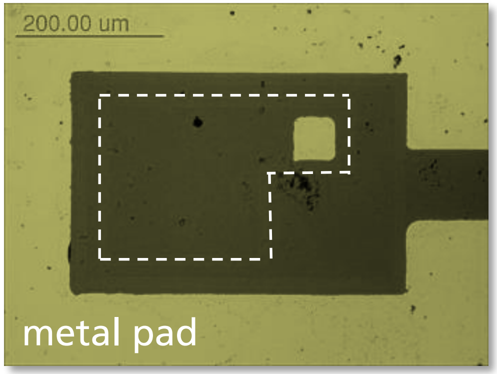
Determination of quality factor via fitting of equivalent circuit parameters



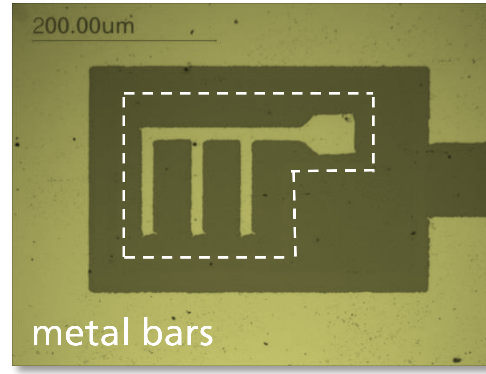


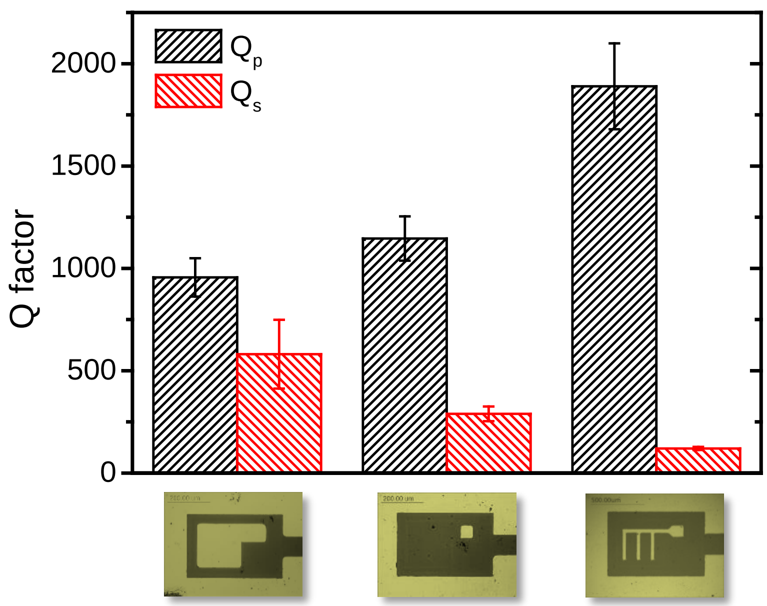
Reduction of viscous losses!

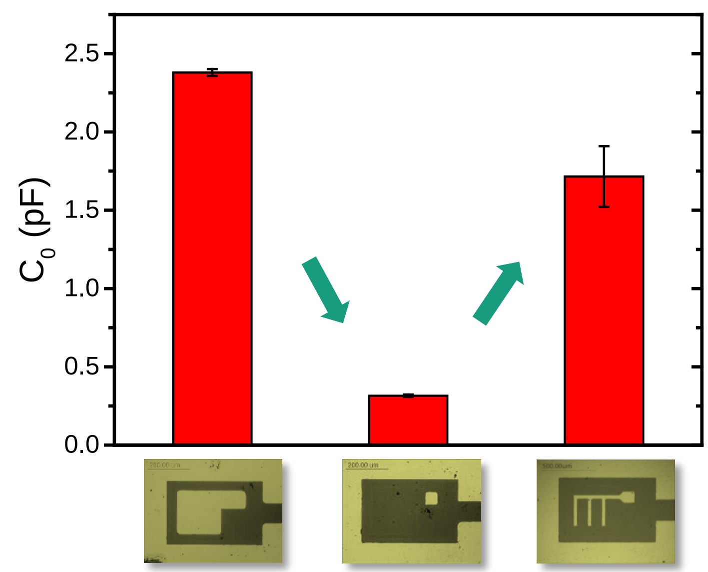
Modifying electrode design



Increase of resonating graphene area







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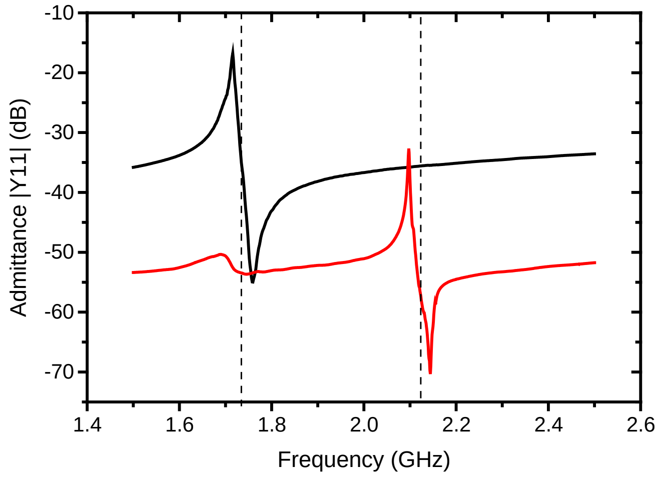
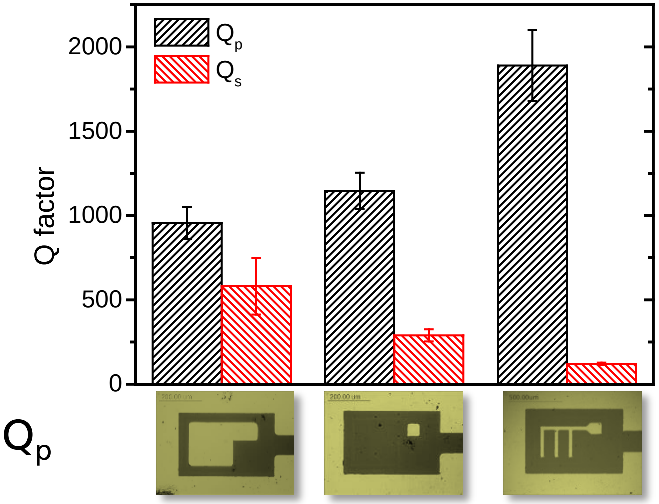
Summary

- Graphene avoids electrode induced frequency shift due to its virtually massless character
- Top electrode metal bar design increases resonating area (C_0)
- Viscous losses are strongly reduced resulting in a significantly increased Q factor for parallel resonance (Q_p)





Outlook

- Further improvements highly probable for graphene with R_s << 2kΩ regarding Q_s and Q_p

➡ Graphene doping, Multilayer graphene

Thank you for your attention!

Thanks to our colleagues at Fraunhofer IAF.

Thanks as well to our project partners, providing us with SMR samples for our graphene research activities.

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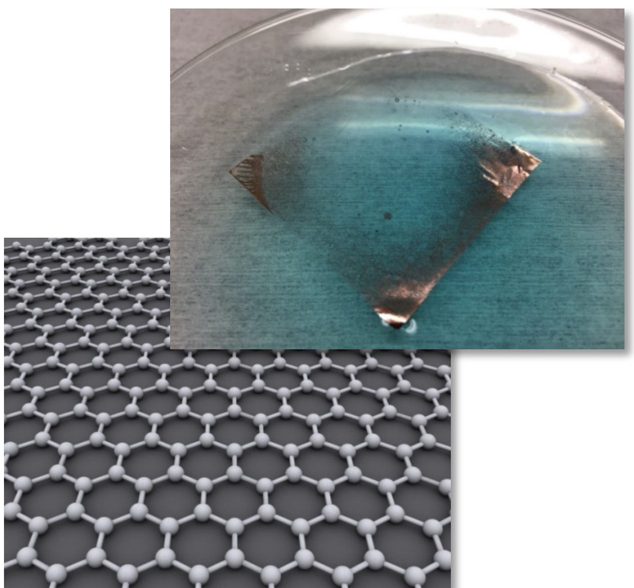

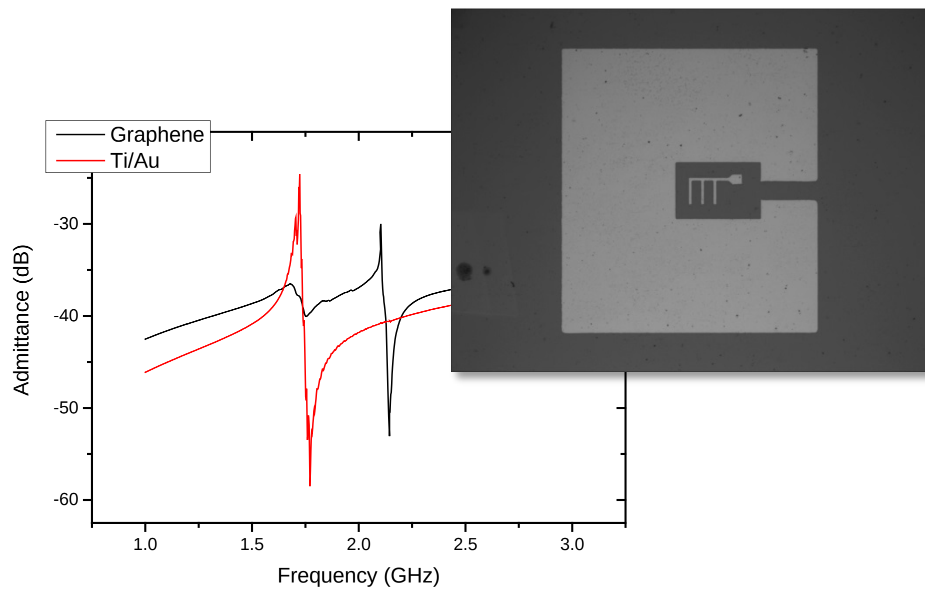

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