GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO

10 ANNIVERSARY

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PECVD Grown Graphene as Transparent Electrode in GaN-based LEDs

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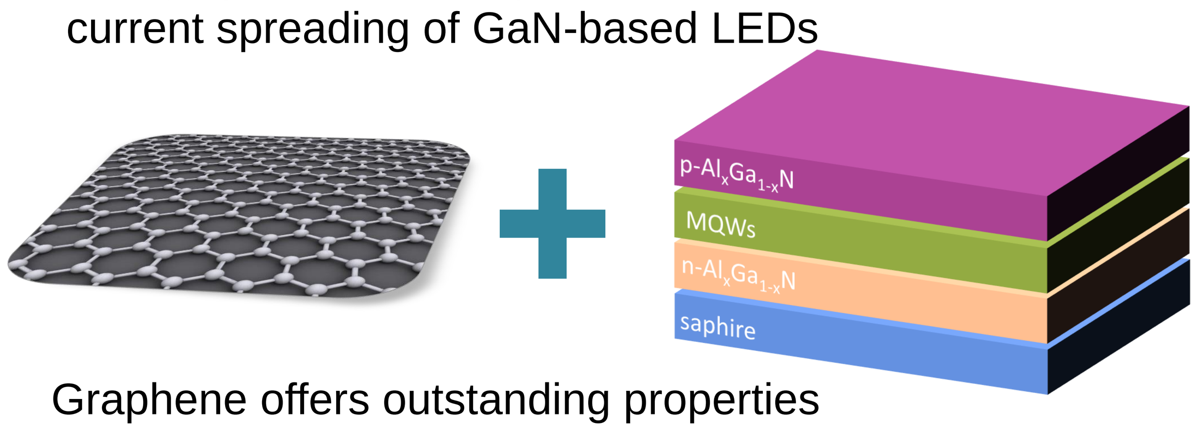
Motivation

Direct growth of graphene on GaN via plasma-enhanced chemical vapor deposition (PECVD) without H_2 atmosphere

Idea

Use graphene as transparent electrode to increase lateral current spreading of GaN-based LEDs



Graphene offers outstanding properties

- High **charger carrier mobilities** (200.000 $cm^2V^{-1}s^{-1}$) [1]
- High optical **transparency** (2.3% absorption per layer) [2]

Using graphene as a transparent electrode on GaN-based LEDs

Challenge

Transfer-free processing of graphene directly on $Al_xGa_{1-x}N$ LEDs without the use of H_2

- "Reverse Epitaxy" destroys GaN surface under H_2 rich atmosphere and high temperatures

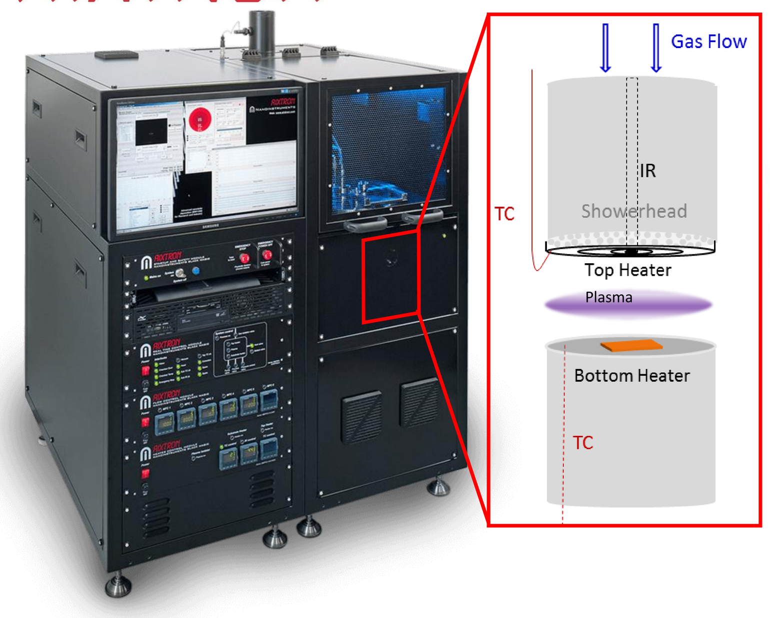
$$GaN + \frac{3}{2} H_2 \rightarrow Ga + NH_3 \quad [3]$$

- N_2 is known to protect the GaN surface under elevated temperatures [4]

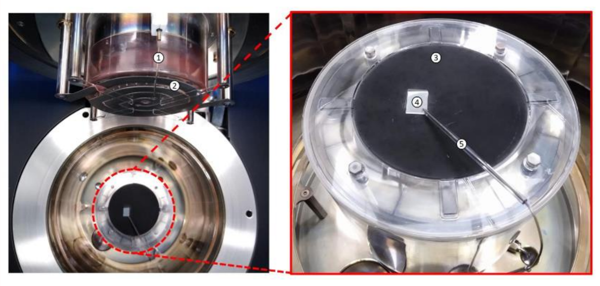
Idea: Switch from commonly used H_2 to N_2 during graphene growth process

PECVD System

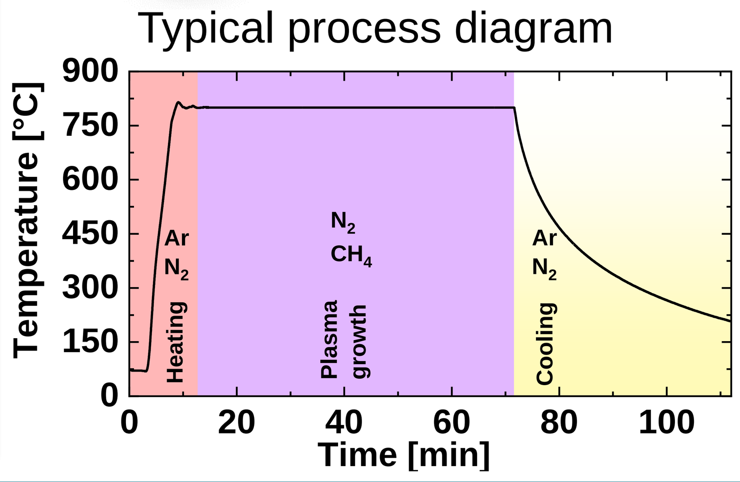
AIXTRON Black Magic 4"



View into the inner chamber

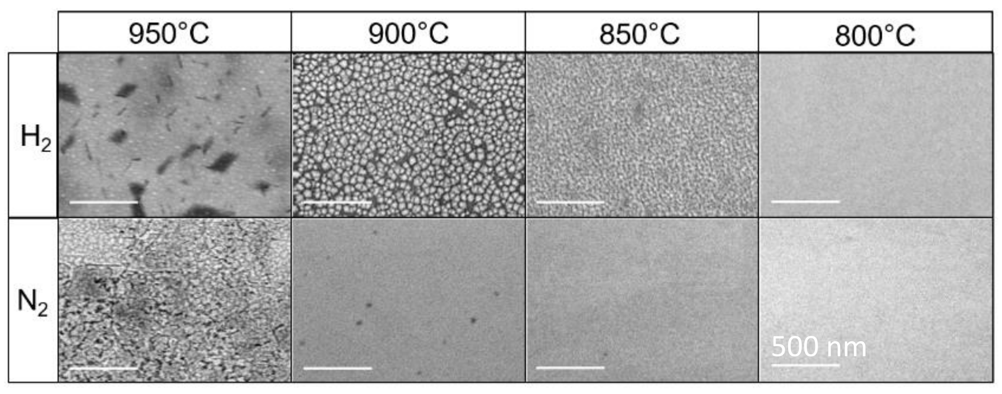


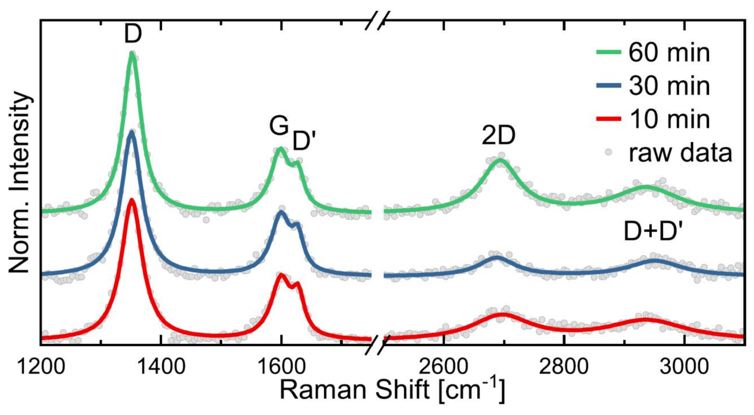
Typical process diagram



- **Homogeneous** gas flow through the showerhead
- Temperature control over the bottom and top heater (**>1000 °C**)
- **Pulsed DC plasma** operation with variable frequency (1-100 kHz possible)

H_2 vs. N_2 atmosphere [5]

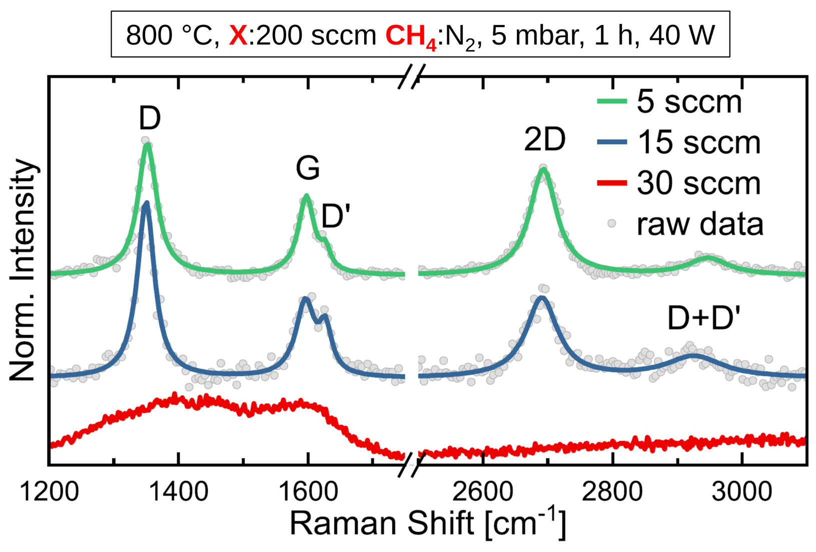


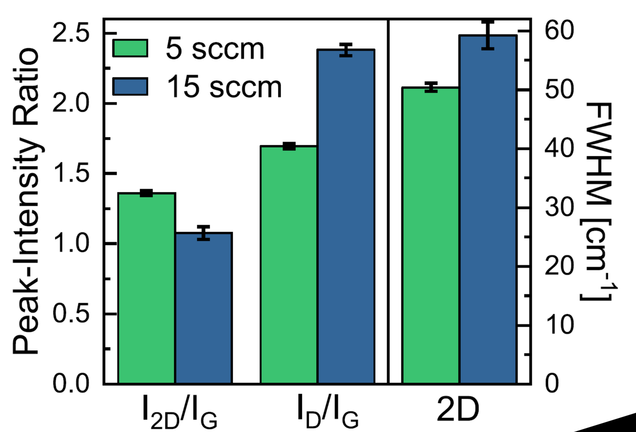


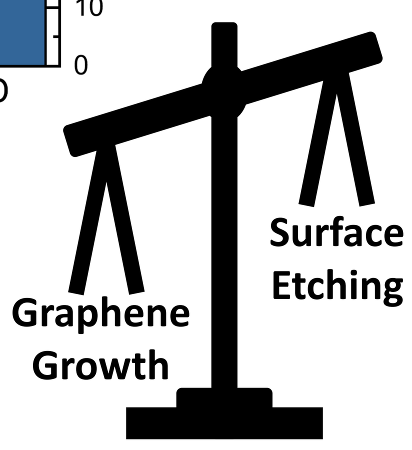
- H_2 atmosphere shows **distinctive etching** of the GaN surface even at lower temperatures
- **No graphene growth** can be observed
- Switching to N_2 atmosphere **protects the GaN surface** from etching effects
- **Graphene growth under N_2 atmosphere** observed
- **Increasing 2D-peak** with increasing growth time

N_2 atmosphere shows promising results in protecting the GaN surface while simultaneously supporting graphene growth

Influence of the CH_4 amount [5]



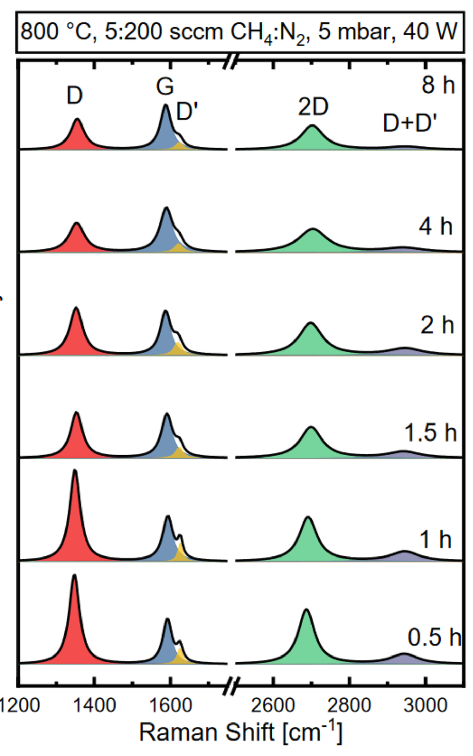


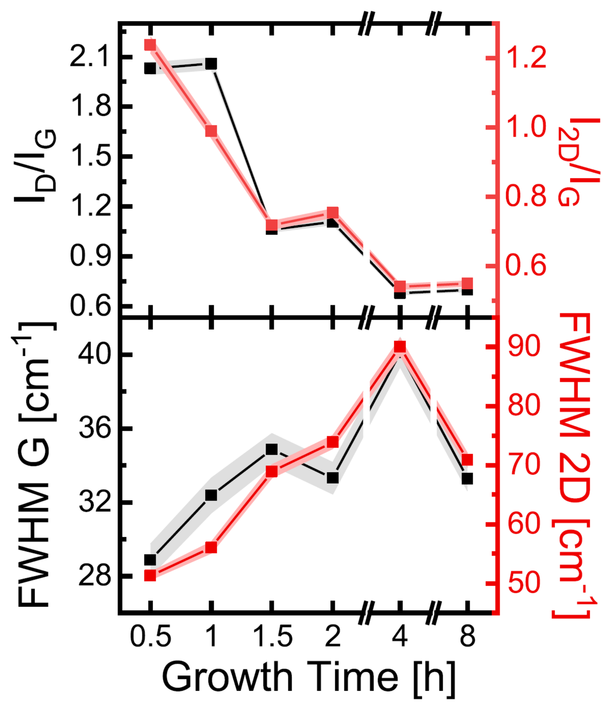


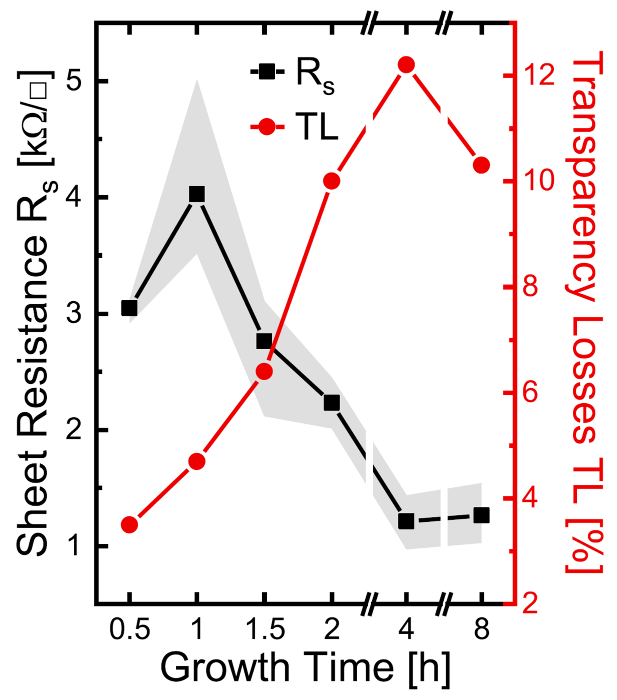
- High CH_4 amount lead to distinctive **etching of the GaN surface** due to free H species
- 5 sccm to 200 sccm CH_4:N_2 offers a **good growth/etch balance** for graphene growth
- I_{2D}/I_G ratios of **> 1.5** achieved

CH_4:N_2 ratio influences the balance between graphene growth and surface etching

Growth time is crucial [5]







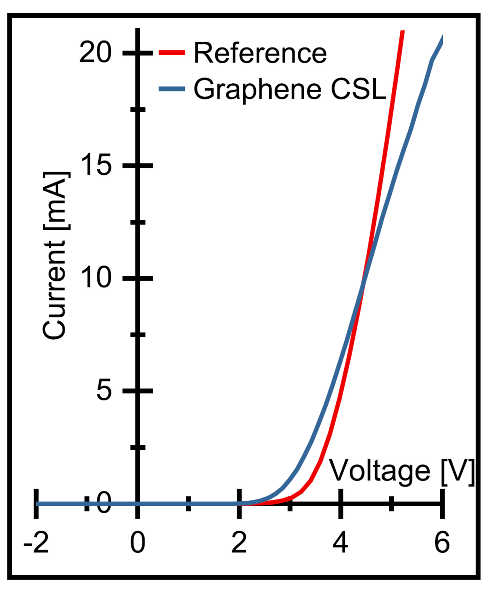
With increasing growth time

- **Decrease** of I_D/I_G & I_{2D}/I_G ratios
- **Increase** in FWHM of G & 2D peaks

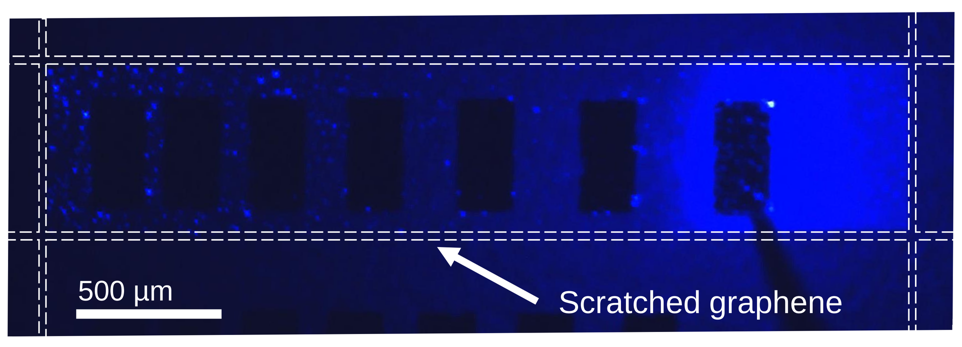
Sheet resistances of **~1 kΩ/□** @ **~12%** transparency losses

Growth of multilayer graphene with increasing growth time
→ Tuning of the sheet resistance of the grown graphene layers

So does it work as intended? [5]



- **Diode-like behavior** after growth process
- **~8 times higher emission** around contact area compared to LEDs without graphene



Graphene electrode shows largely increased emission area across the LED surface

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