Structuring graphene as an electrode for organic light emitting diodes: challenges and outlook

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Motivation

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cessary (photo resist and

- Alternatives need to be:
  - Inexpensive, fast, reproducible and reliable

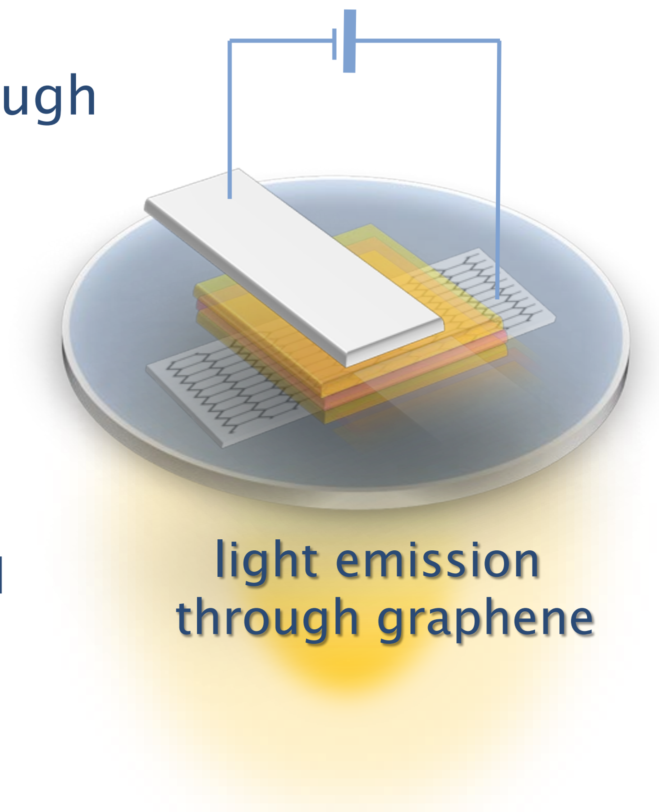
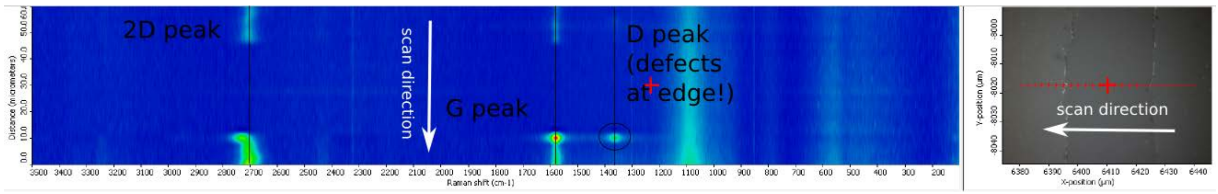
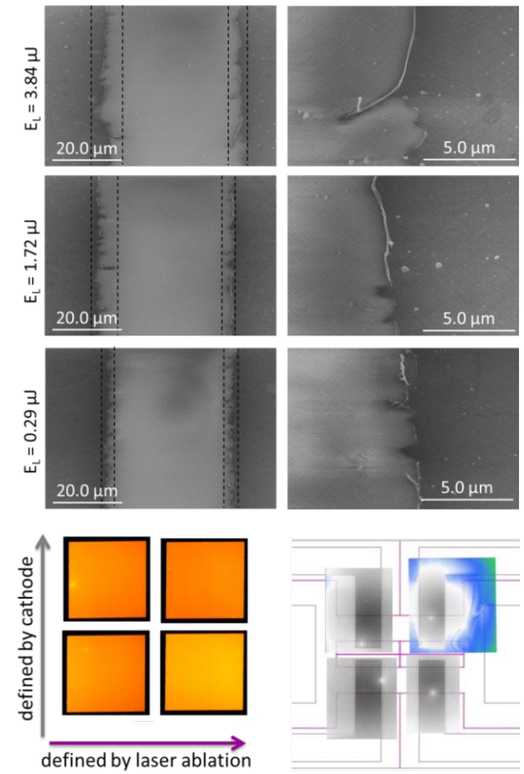


Figure 1. Working principle of organic light emitiing diodes using graphene as electrode.

Laser ablation

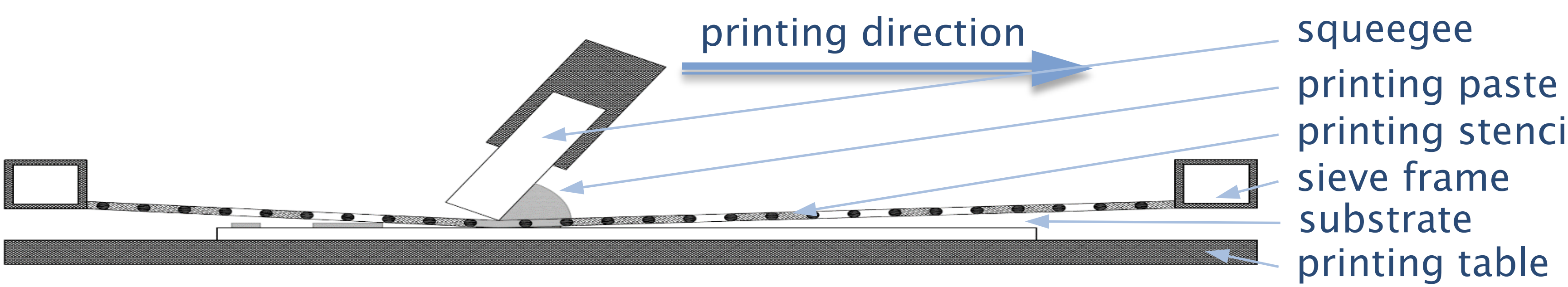


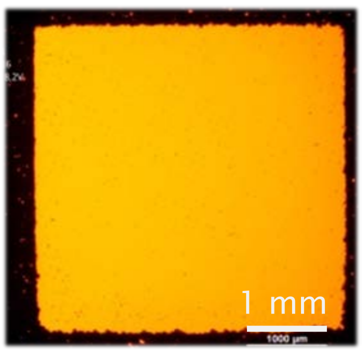


- Locally very high temperature → formation of 2-3 µm thick folds
  - Induces short circuits → resulting in „sudden death“
- By varying the laser fluence, length and number of these folds varies
- Applied on foils, sacrificial layers are needed to protect the barrier layer

Figure 2. (Top, right) SEM pictures of graphene edges on glass after laser ablation in dependence on the radiant fluence, (bottom, right) as well as correspoding thermographic images of resulting OLED devices. (Left) 2D Raman map of seperated graphene layers by laser ablation.

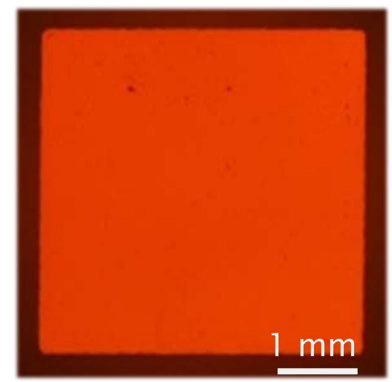
Screen printing





changing screen printing ink and printing parameters

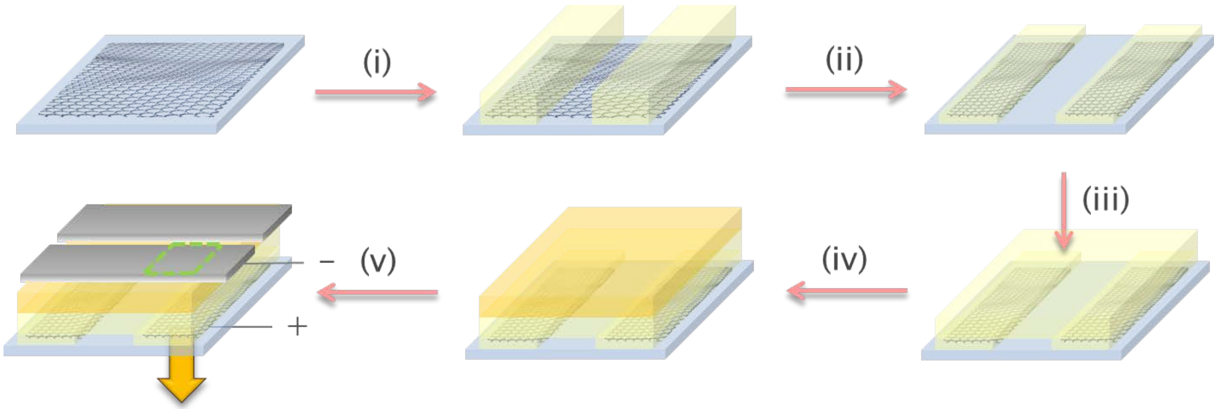
- Improving sharpness of edge
- Reducing ink residues on active area



Scheme 1. (Top) Working principle of screen printing and (bottom) examples of OLED devices using graphene as electrode when passivated by screen printing.

- Wetting behavior strongly depended on screen paste and contact angle of surface

Plasma etching (I)



Scheme 2. Schematic presentation of the device fabrication: the bare anode (here graphene) is provided on an insulating substrate, where a hole transport layer (i) with a specified shape is deposited on the anode. (ii) Afterwards an Ar/O_2 plasma is shortly applied to both the organic layer and graphene electrode and stops after the graphene is entirely etched away, followed by the deposition of a hole transport layer (iii) and other functional layer necessary to complete the OLED (iv). By subsequent deposition of the cathode, the emitting area of the OLED is defined.

- CVD graphene transferred by chemical etching
- Deposition of 20 nm of a hole transport layer (HTL)
- Application of Ar/O_2 (1:1) plasma for 120 s → thickness reduction of HTL by 9.1 ± 0.1 nm
- Subsequent deposition of HTL, blocking and emission layer followed by hole blocking and electron transport layer

Plasma etching (II)

- Plasma etching shows no impact on OLED lifetime
  - Two different types of HTL layers have been tested
  - Variation of different plasma exposure times
- Repetition for graphene electrodes

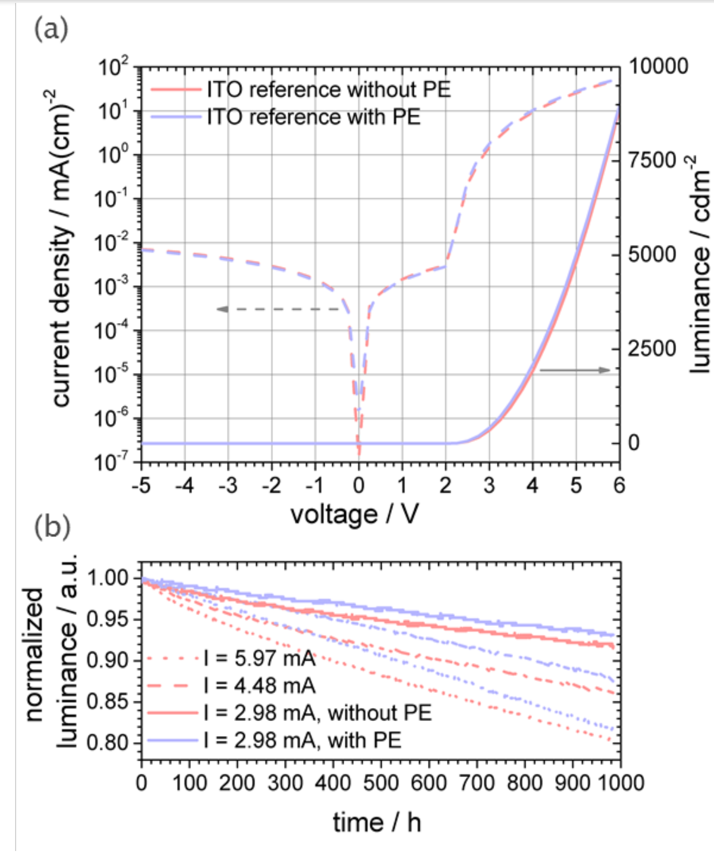


Figure 3. (a) Luminance-current density-voltage (LJV) curves of ITO reference samples containing a hole transport layer which has not experienced any plasma etching (light red) and which has (light blue) as well as the corresponding luminance decay curves determined at three different currents.

Plasma etching (III)

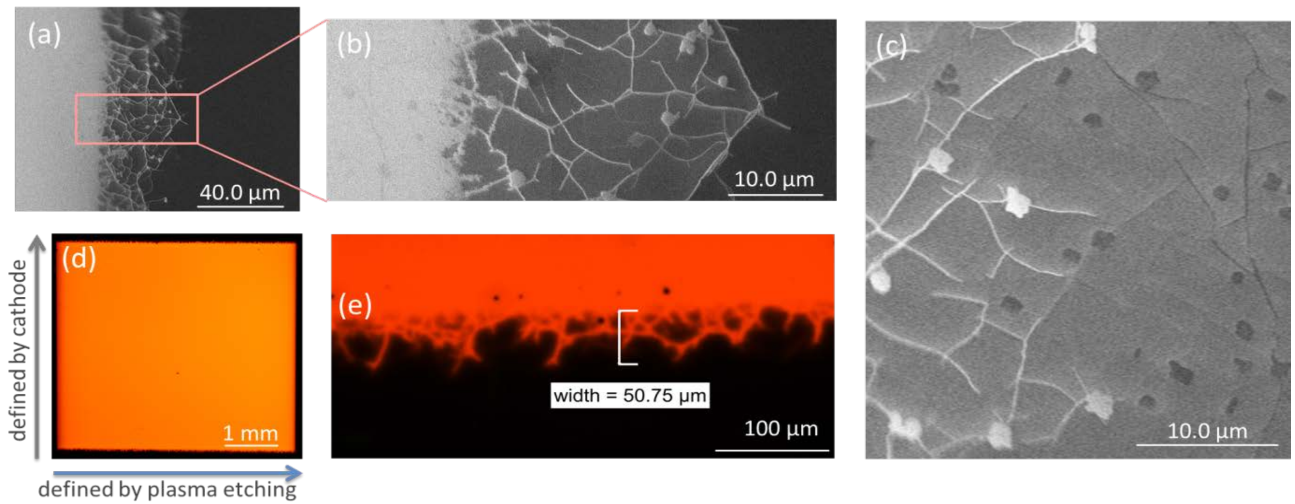


Figure 4. (a) and (b) present SEM images after the plasma has been applied for 120 s resulting in an HTL reduction of 5.1 nm: on the left side a 15 nm thick, amorphous HTL layer (light grey) is seen with a 40 – 50 µm wide transition zone. (c) detailed image of (b) indicating the presence of graphene islands and boundaries. (d) and (e) present microscopy images of resulting OLED devices demonstrating that this transition zone has a width of the same magnitude.

- Uncovered graphene became non-conductive
- Formation of a 40-50 µm thick „frayed“ transition zone
- Indications that graphene is not removed, just oxidized and aromatic lattice is destroyed (→ much lower conductivity)

Summary & outlook

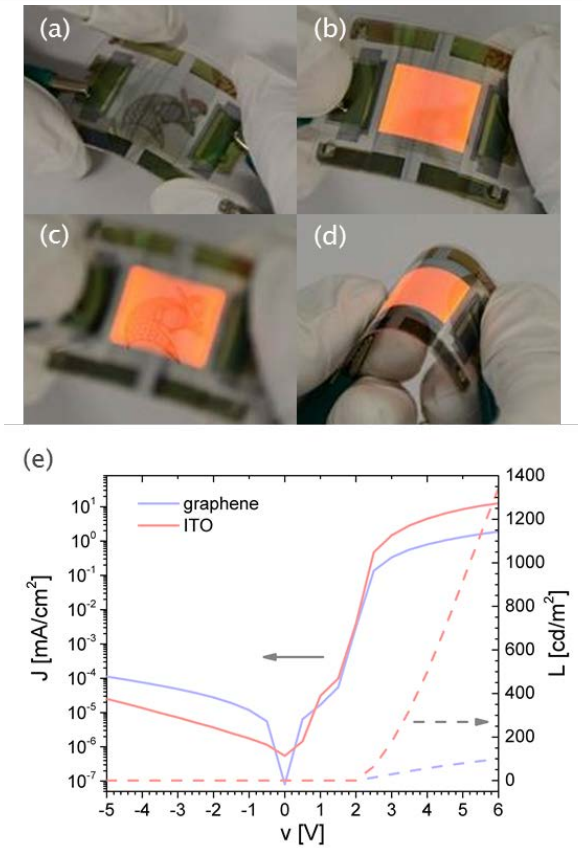


Figure 5. Example of a flexible, transparent OLED with an emitting area of 1.5×2 (cm)² after patterning it by plasma etching (a–d) and its JV characteristic compared to the ITO reference.

Table 1. Overview of 3 cm² OLED performance for both graphene and ITO .

3 cm² OLED	100 cd/m²					
electrode	v [V]	CD [mA/cm²]	CE [cd/A]	LE [lm/W]	EQE [%]	J(−5 V) [mA/cm²]
graphene[a)]	6.1	1.9[)]	5.3	2.7	4.1	1.1×10^{-4}
ITO[b)]	2.7	0.8	13.3	15.9	10.3	2.5×10^{-5}

[a)] has been structured by plasma etching; [b)] has been structured by laser ablation.

- Plasma etching is a useful method to define the graphene anode
- In particular feasible on polymer foils (does not harm the barrier layers)
- Independent on surface energy of graphene (i.e. wetting behavior of screen printing inks)
- Works for OLED devices from small (6.4 mm²) to large (3 cm²) areas

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