Dual frequency diffuse dielectric barrier discharge for atmospheric-pressure thin film deposition

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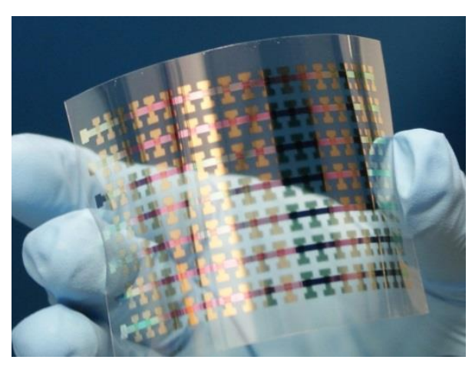
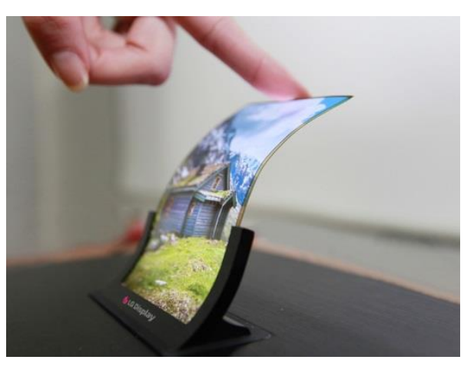
Introduction

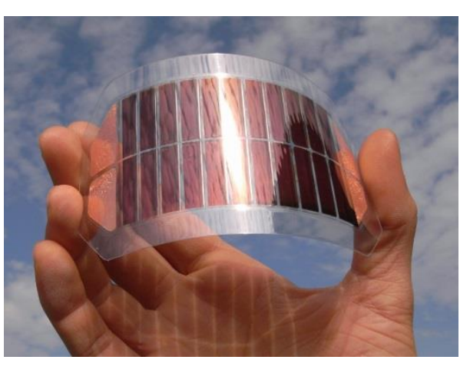
Flexible electronics:



TFT

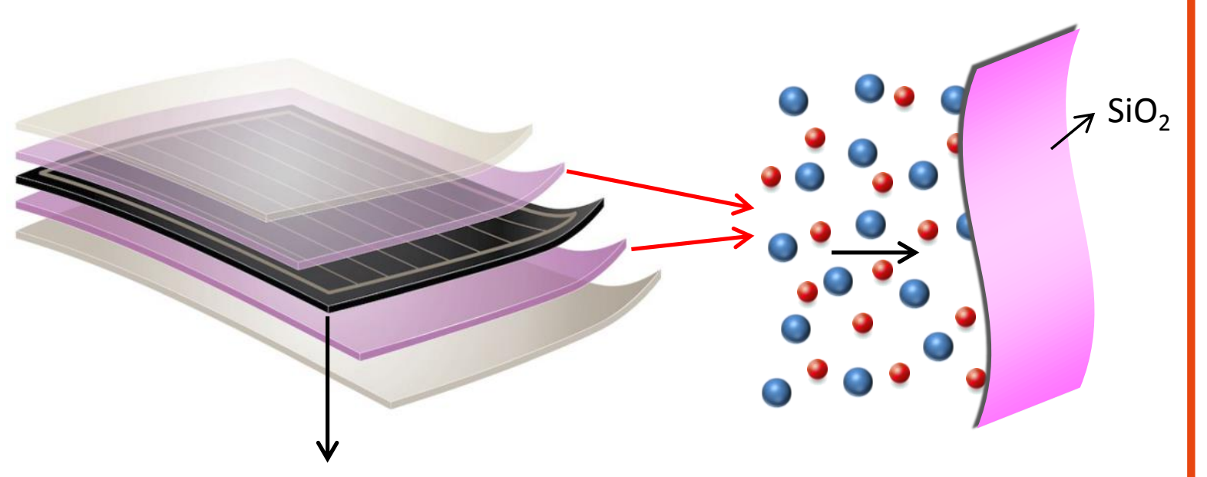


OLED



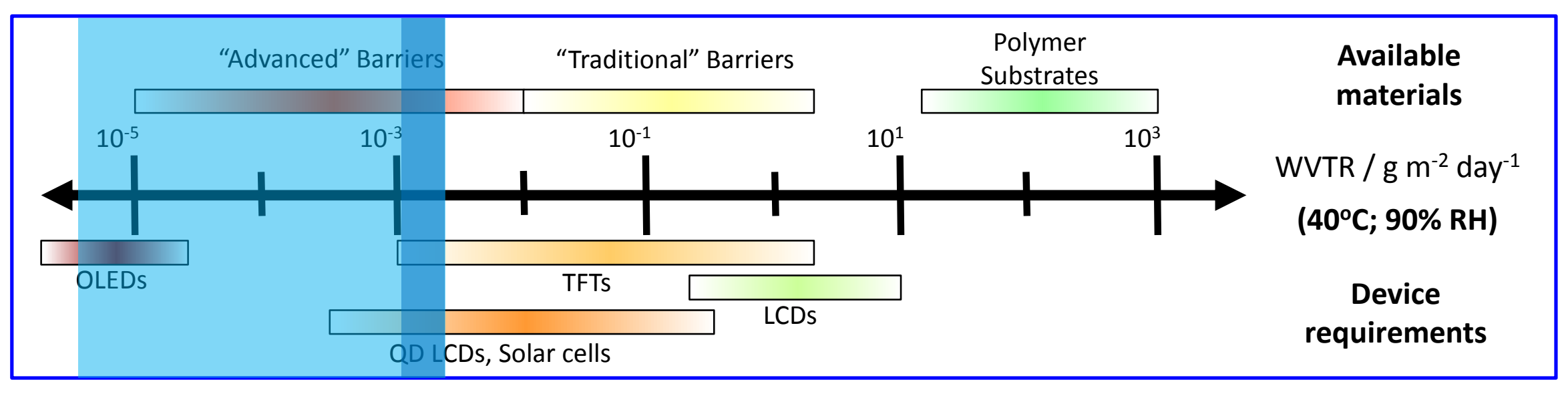
Solar cell

Encapsulation foil:



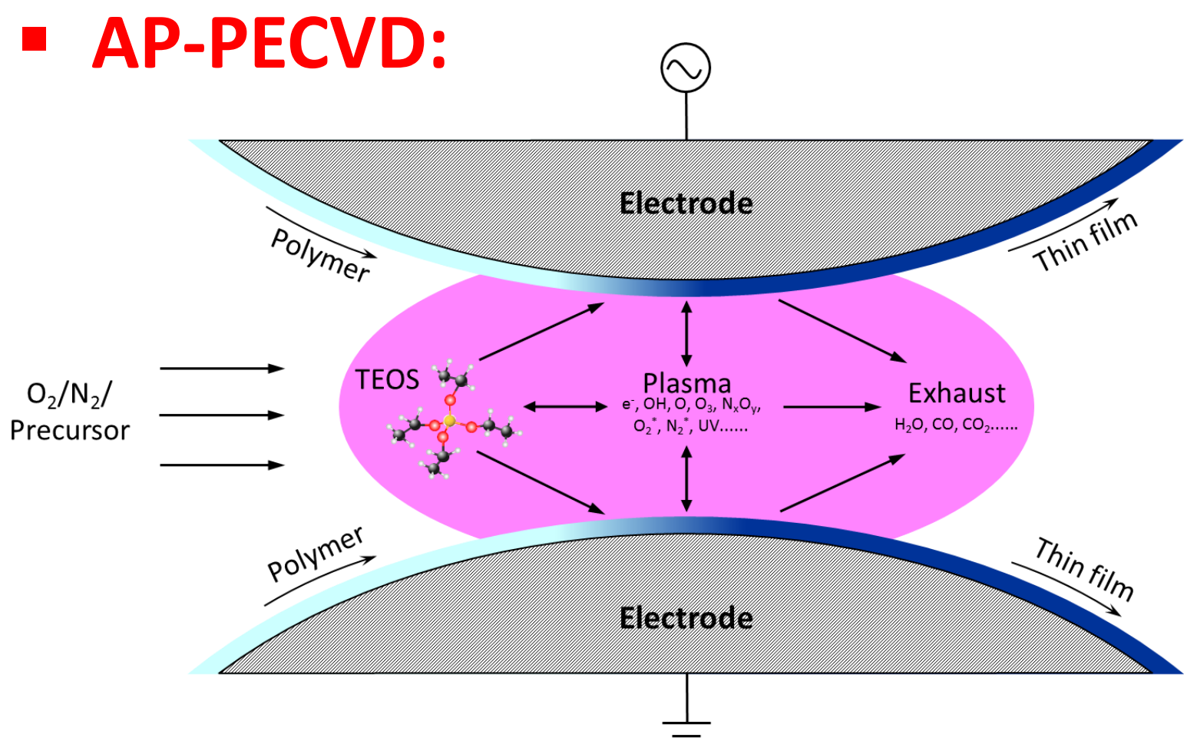
Solar cell **Encapsulation foil**

Requirements:



- **Higher performance** (lower **WVTR**)
- **Higher throughput** (at least **10 times**)
- **Lower costs**

AP-PECVD:

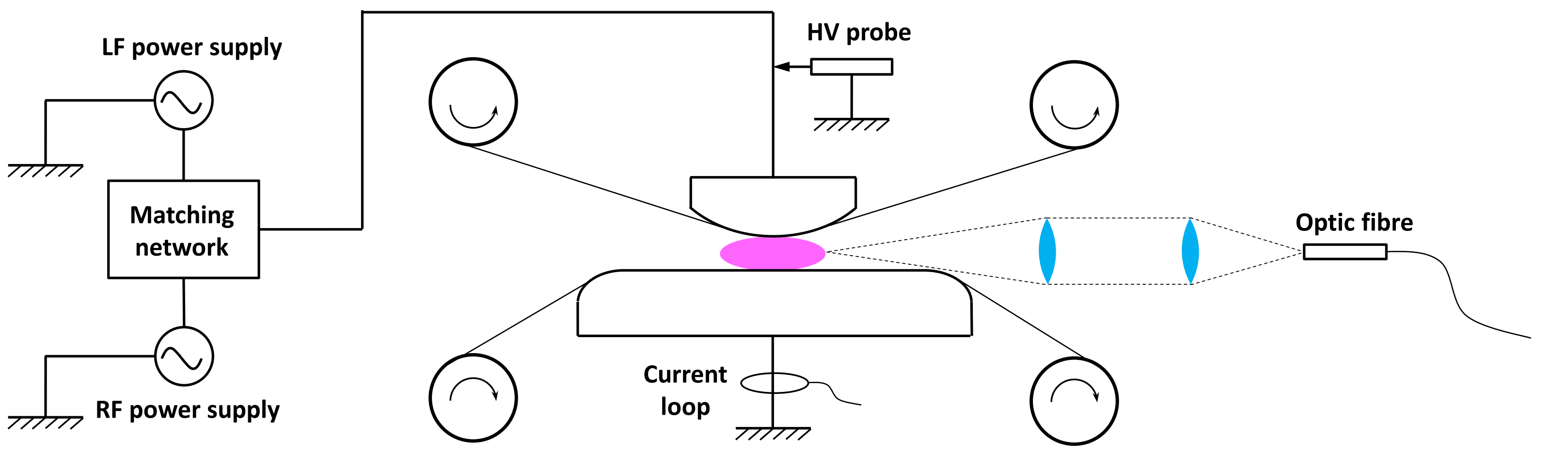


- **Atmospheric-pressure** (**low costs**)
- **Roll-to-roll** processing (**high throughput**)
- Precise control over **thin film properties** (**uniformity**, **porosity**, **morphology**……)

Dual frequency (DF) power supply:

- In order to increase the **efficiency** and the **throughput** of PECVD processses, the **plasma power** should be further **increased**.
- By using **dual frequency** (**DF**) power supply, the **ion energy** and the **ion flux** to the substrate can be independently controlled by the **low frequency** (**LF**) power and **high frequency** (**HF**) power, respectively.
- In this work, we intend to study the **discharge characteristics** and the **thin film properties** using the **dual frequency (DF)** power supply under **AP-PECVD** conditions.

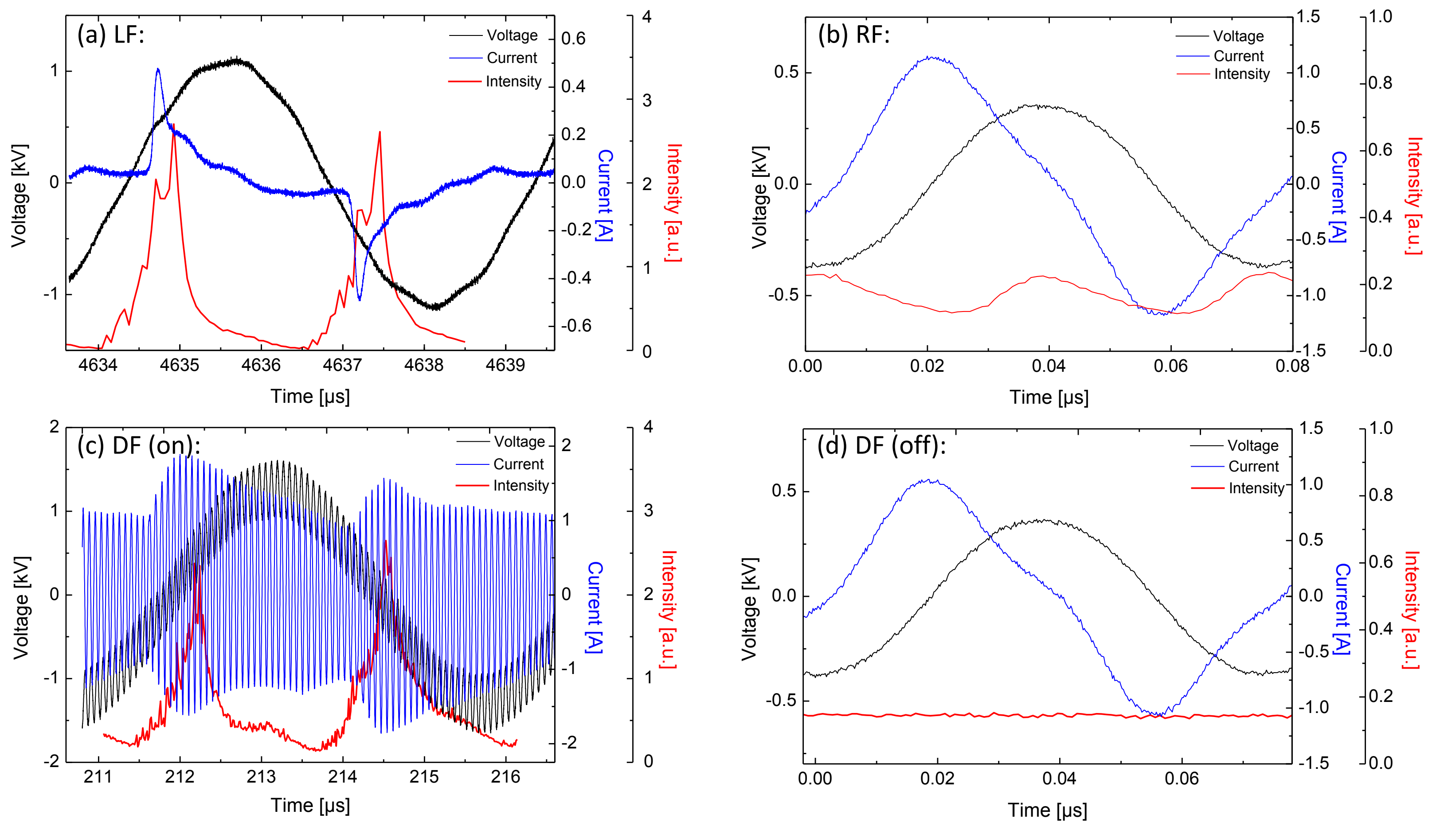
Experimental Set-up



- Gas mixture: Ar, N_2/O_2
- Gas gap distance: 0.5 mm
- Substrate: PEN
- Power density: ~ 10 W/cm²
- Voltage amplitude: 1~2 kV
- Precursor: HMDSO

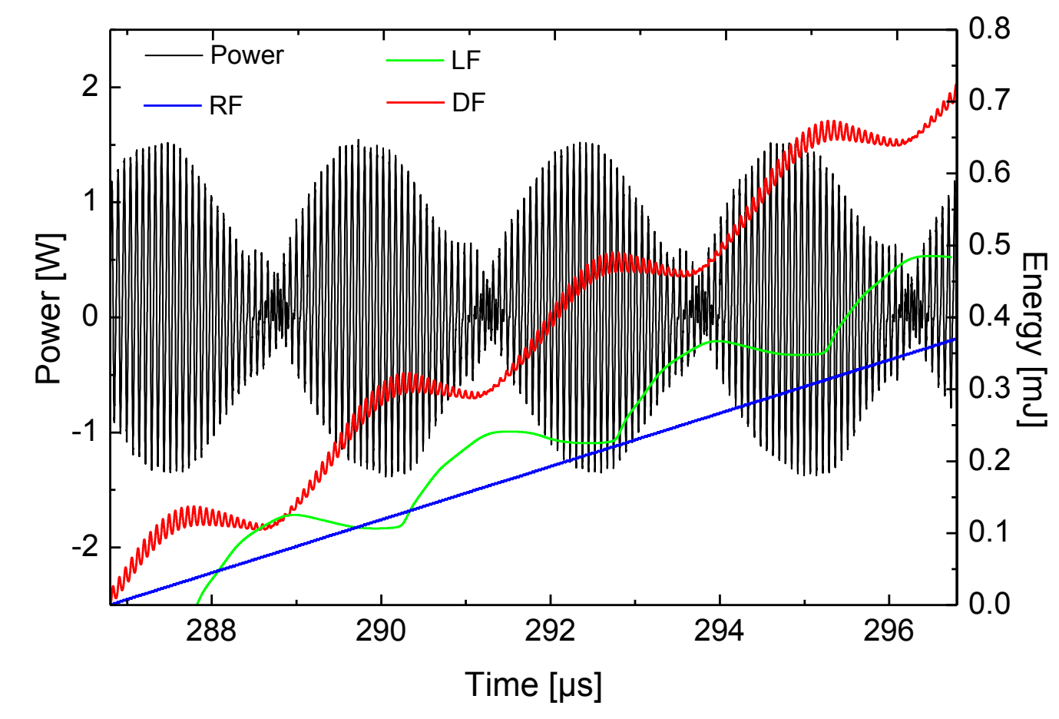
Results & Discussions

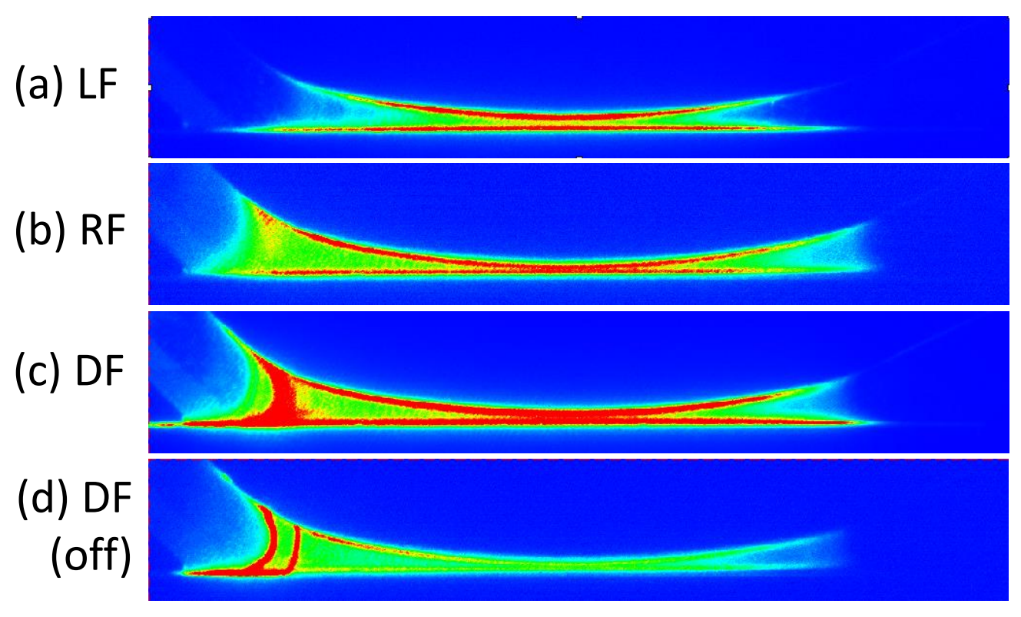
UI and emission in DF plasma:



- By introducing an extra **RF** power to the **LF** power, **more power** can be input into the plasma. The **DF** plasma is like a coupling of LF and RF plasma according to the ***UI*** waveforms and the time-resolved **discharge emission**.
- The **discharge emission** is in an agreement with the **discharge current** in **LF**, **RF** and **DF** plasma. During the "**off**" period of **LF** between adjacent pulse trains, it is surprising to observe the **residual emission** which is not synchronized with the current waveform.

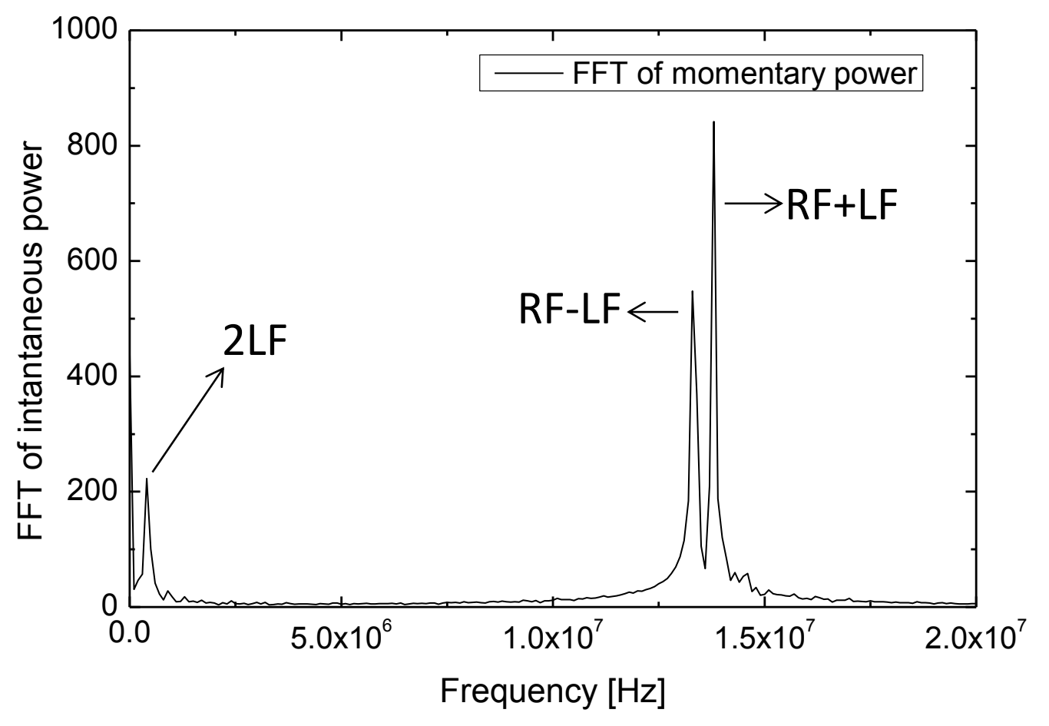
Discharge power and emission:

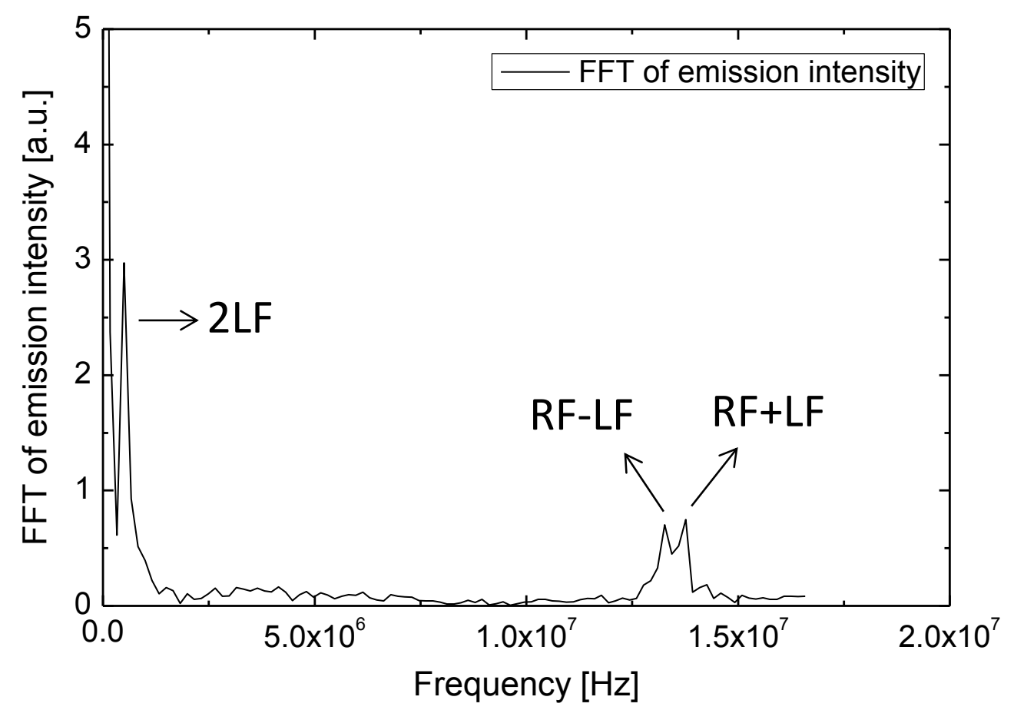




- The discharge area and the intensity of **DF** plasma is obviously enhanced with extra **RF** power.
- The **DF** power (**~70 W**) is lower than **LF+RF** (**~45 W+~38 W**) power , which is probably due to the **matching network** not ideally working as well as the **residual discharge** during the "**off**" time of LF voltage that also consumes power (as shown in the discharge emission imaging (d)).

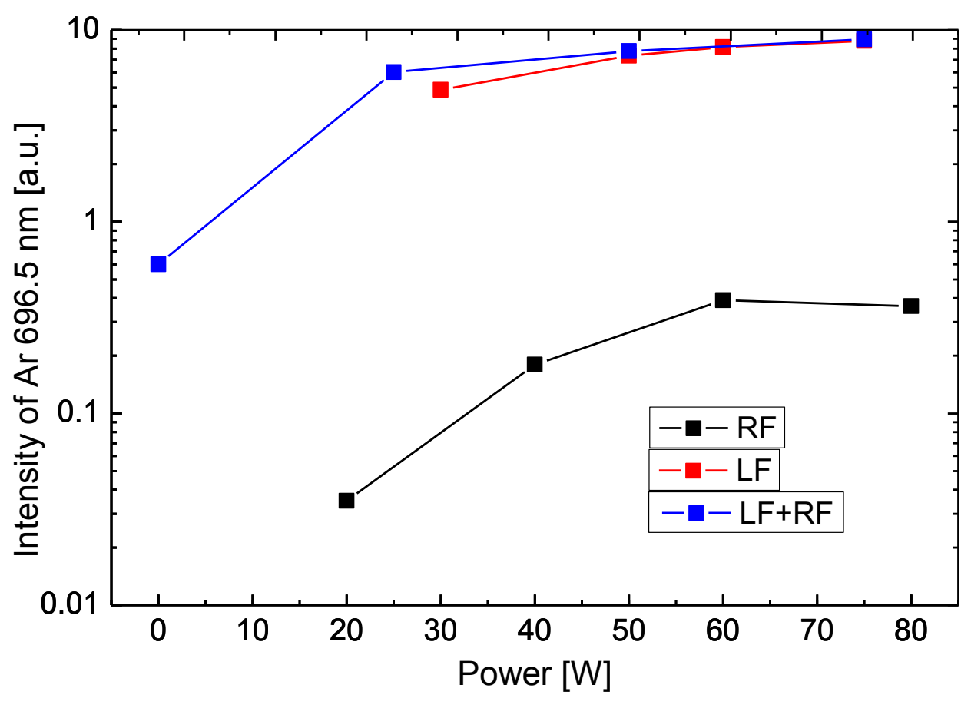
FFT of momentary power and emission:

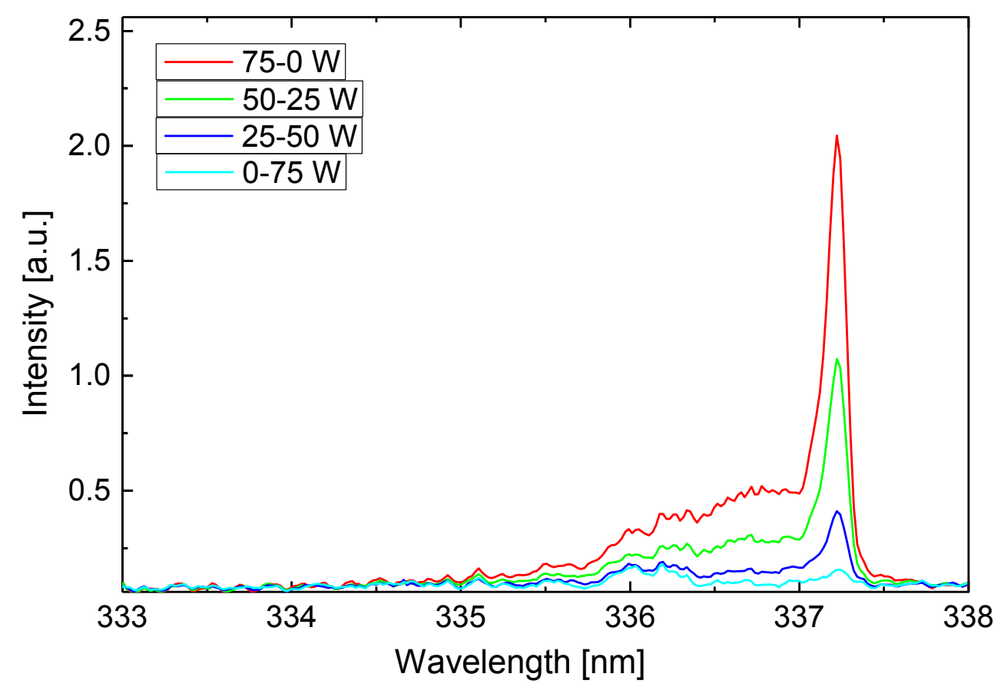




- The **Fast Fourier Transform** (**FFT**) of the discharge **emission intensity** in the **DF** plasma is in agreement with that of the **momentary power** (***P***=***U***×***I***). The frequency **2LF** is due to the **LF** power, while the **FFT** at **RF±LF** indicates a **coupling** between **LF** and **RF** frequencies.

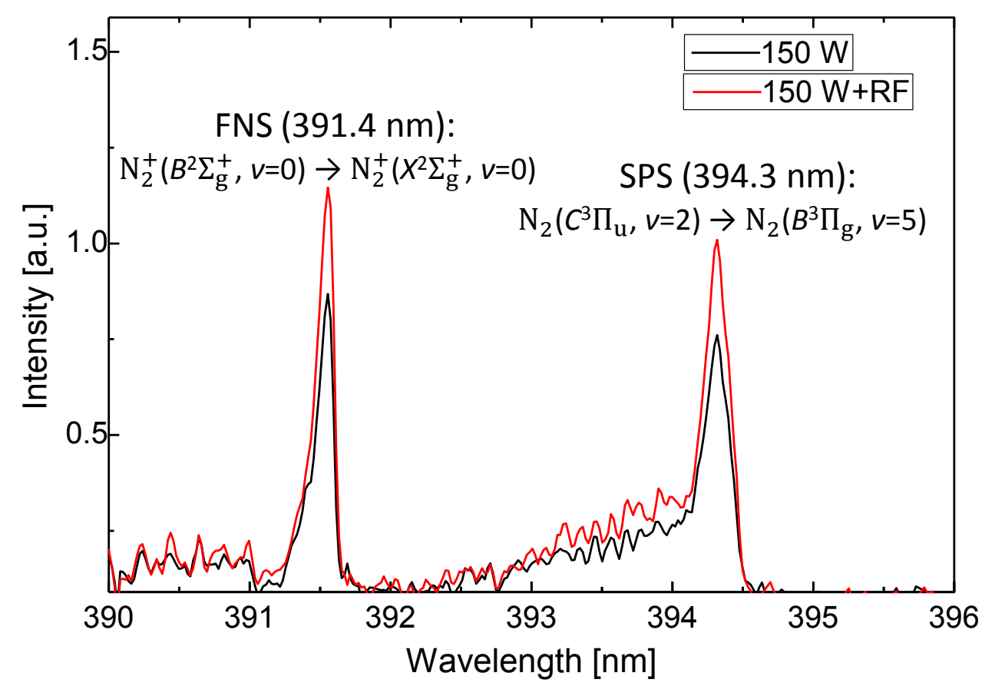
OES of Ar plasma:





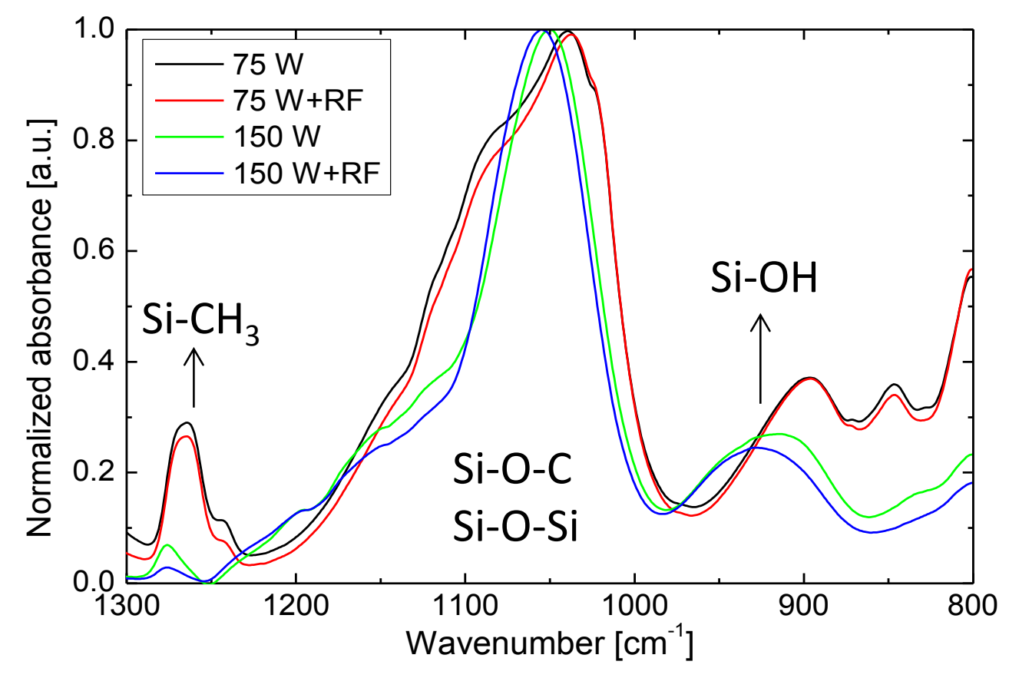
- **Ar 696.5 nm (3p⁵4p → 3p ⁵4s)** and **N_2 337 nm** (**$C^3\Pi_u$ → $B^3\Pi_g$**) are due to the **high energy electrons** (**~13 eV and ~11 eV**, respectively). In the **DF** plasma, it is mainly the **LF** power that contributes to the increasing of the **high energy electron density** (***n_e***).

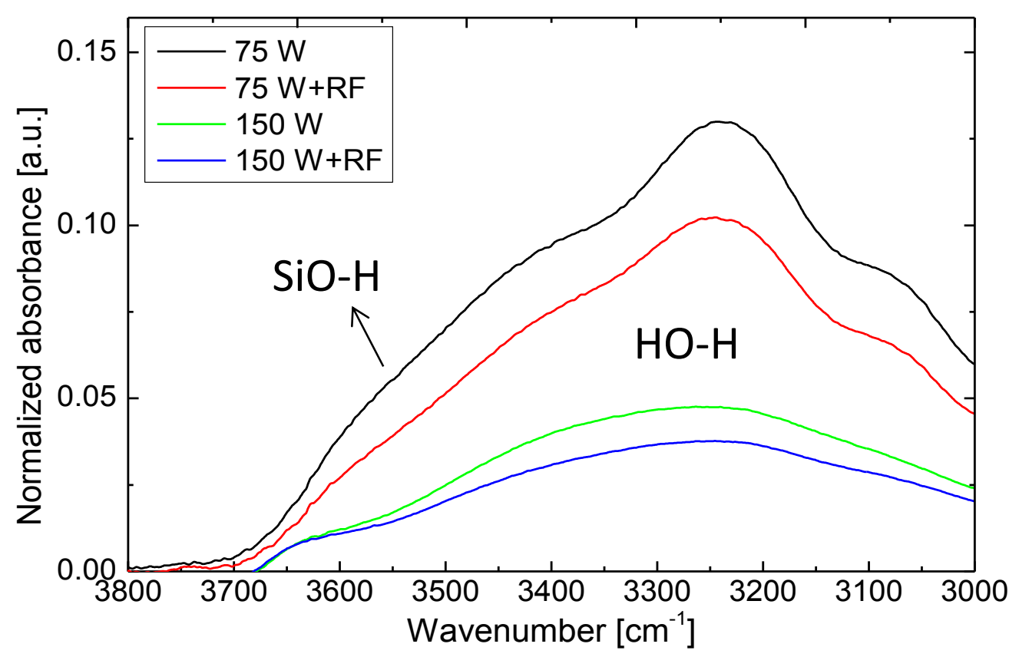
OES of N_2/O_2 Plasma:



- In N_2/O_2 plasma, the **reduced electric field** (***E/N***) is similar with **LF** and **DF** power (***$R_{391nm/394nm}$*~1.2**, ***E/N*~1000 Td**). With the special electrical circuit in this setup, the **voltage** is relatively constant while the **current density** is higher when the **power** increases.
- The high value of ***E/N*** is probably due to the fact that it is estimated according to the integrated emission which is higher near the **sheath** where the **electric field** is much higher than the other area.

ATR-FTIR measurement of the thin film:





- With higher power, there is less **C, HO-H, Si-CH_3** and **Si-OH** in the thin film, therefore an improved **Si-O-Si** network. Compared with **RF** power, **LF** power improves the thin film property more significantly.
- The **high energy ions**, which are important to the deposition, are mainly induced by the **LF power**.

Conclusions

- By coupling an extra **RF** voltage to **LF** voltage, **more power** can be input into the plasma **without arcing**.
- Because of the electrical circuit in this study, the **voltage amplitude** is relatively **constant** while the **current density** increases with the input power. As a consequence, **the reduced electric field** (***E/N***) as well as the **electron temperature** (***T_e***) do not obviously increase with either **LF** or **RF** power.
- The **thin film deposition** is influenced by the power input: with higher power, there is less **Si-O-C, HO-H, Si-CH_3** and **Si-OH** in the thin film, therefore an improved **Si-O-Si** network. The **high energy ions,** which are mainly induced by the **LF** power, play an important role in the deposition.