# Characterization of a Flexible Surface DBD Device

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## Abstract

We characterize the behavior of a flexible surface dielectric barrier discharge (DBD) device operated in ambient air at low duty cycles (< 50%). The device exhibits latencies of the order of seconds between turn-on and the beginning of glow activity, and its discharge current is influenced by external airflows of the order of a few m/s. We tentatively attribute the former effect to water desorption and the latter to changing metastable densities over the device.

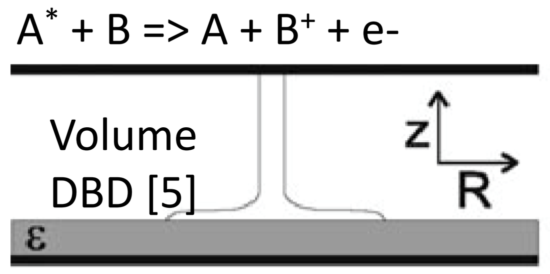
## Introduction

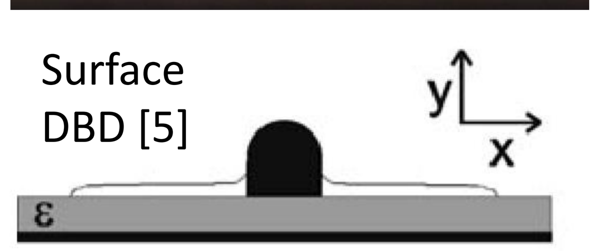
- DBD – Cold, nonthermal plasma at 1 atm; typical [1]:
  - $T_e \sim$ 1-10 eV, $T_g \sim$ average gap temp. ~ room temp.
  - $n_e \sim 10^{14} - 10^{15}$ cm$^{-3}$
- Dielectric barrier restricts current flow [2]; charge accumulation on barrier "chokes off" discharge.
- Individual discharges:
- 10-100 ns, 0.1 – 1 nC [1]

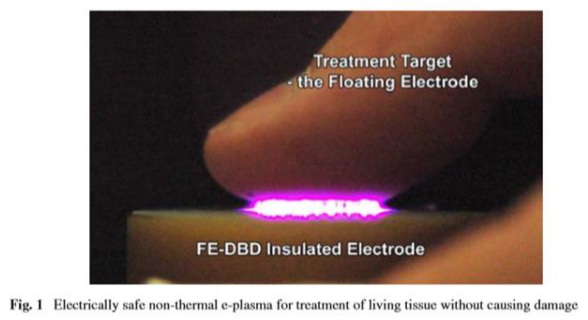
Relevant electron production processes [3]:

- A + e- => A+ + e- + e-
- A* + e- => A+ + e- + e-
- A* + B => A + B+ + e-

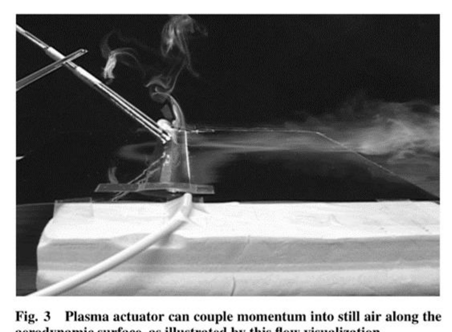
DBD Side View [4]




Medical applications [6]

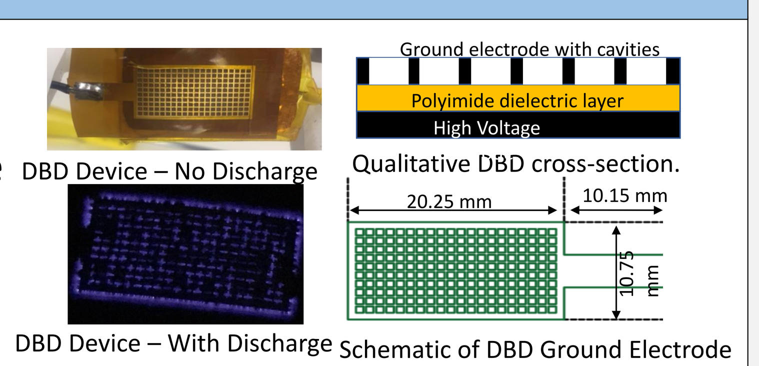


Airflow control [7]

- Light production [8], surface treatment [9]
- For applications, behavior in open air is important
- Interesting phenomena arise when device is operated at low (0.1 – 0.5) duty cycles

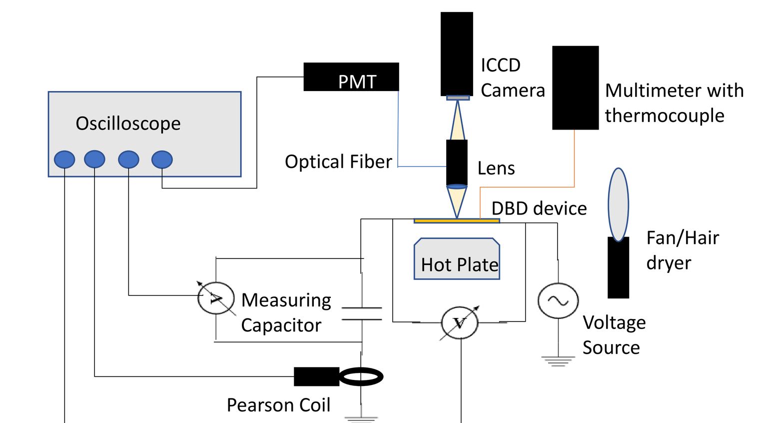
## Experimental DBD Device

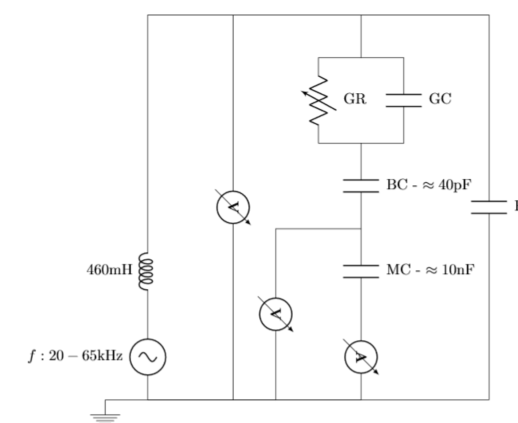
- DBD design:
  - Surface discharge
  - Cavity array
- DBD device:
  - HV electrode (flat copper tape)
  - Dielectric layer (Kapton, 100 µm) ($\epsilon_{rel} \approx 3.5$)
  - Patterned ground electrode, ENIG coated, 30 µm thick
- 200 (10x20) square cavities in ground electrode (s = 700 µm)
- $C \sim A\frac{\epsilon_{rel}\epsilon_0}{d} \approx 60\ pF$

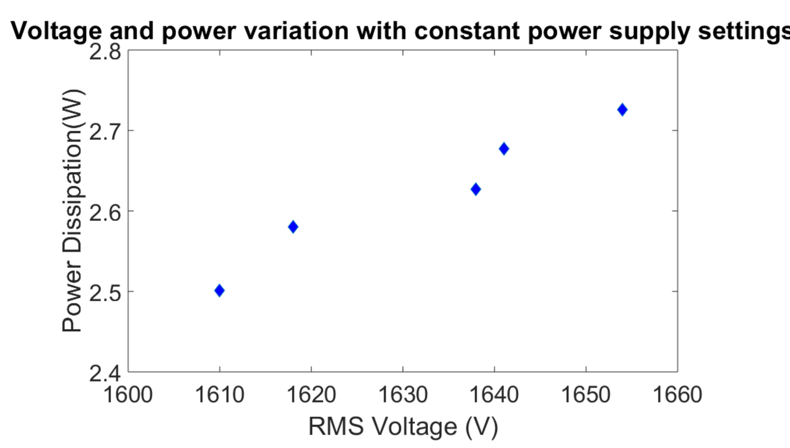


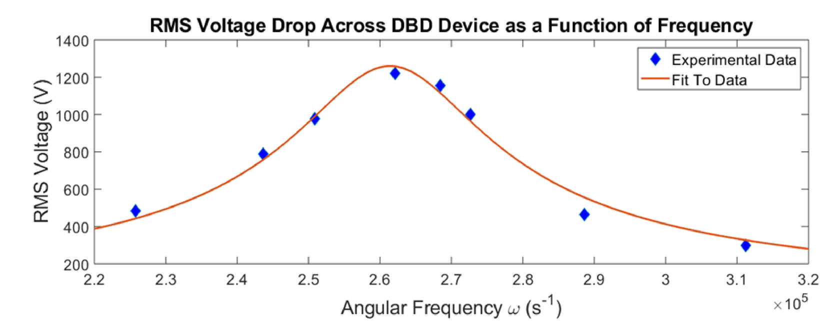

## Experimental

- Typical voltages: 2 kV AC, 40 kHz (resonance), Typical duty cycles: 0.1-0.5
- Measure voltage drop, current to ground, charge, and light from surface.
- Measure dissipated energy with V-Q Lissajous figures [10]
- Resonance FWHM: $\Delta\omega = 23{,}000\ s^{-1}, \Delta f = 3.7\ kHz$
- Changes in $C \rightarrow$ changes in $\omega_{res} \rightarrow$ changes in $V$ at constant $\omega$
- $\Delta V > 50\%$ over time for resonance; $\Delta V \sim 1\%$ even at steady state



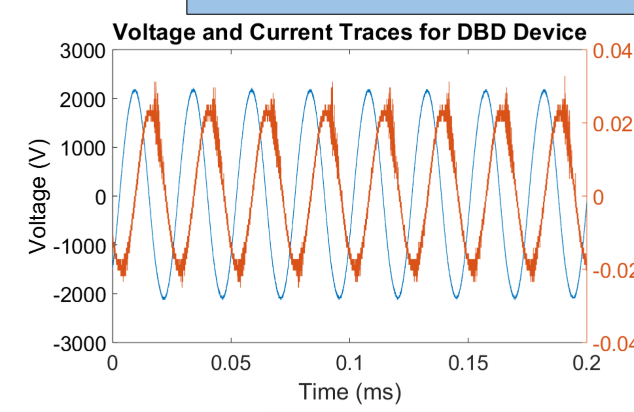


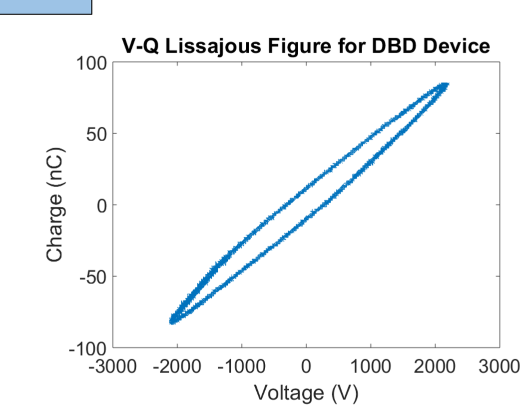



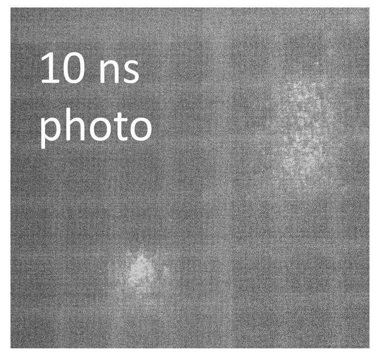

## Results

### Basic Characteristics

- Parallelogram V-Q figure, discharge "spikes" [2]
- $C_{dis} \approx 40 - 50\ pF, C_{off} \approx 30 - 40\ pf, P_{dis} \approx 3\ W$
- Fast photos: diffuse glows in cavities

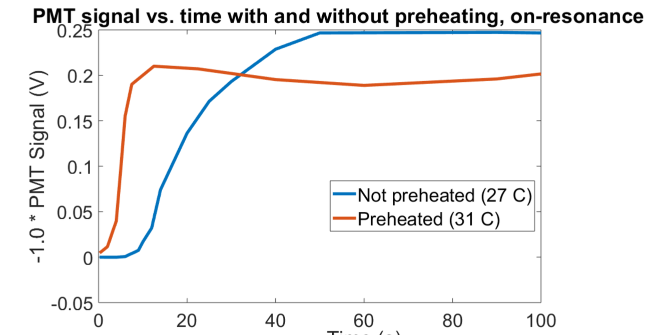


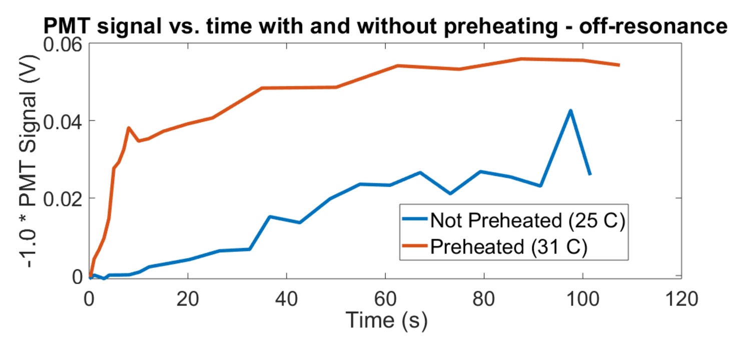



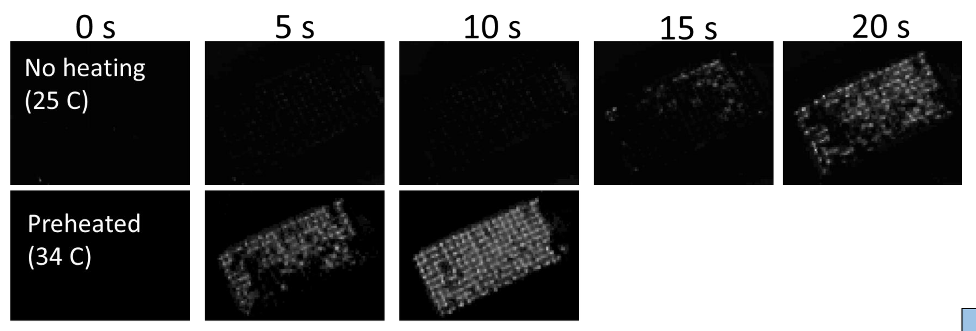



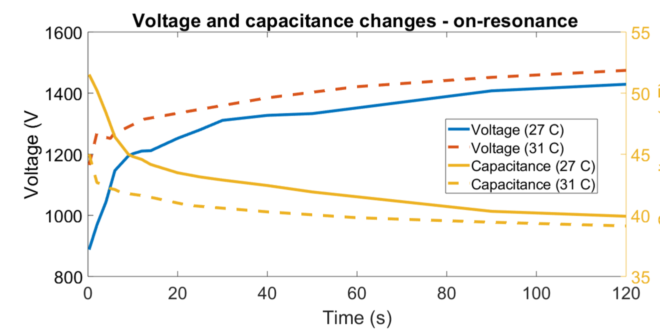

### Glow Latency

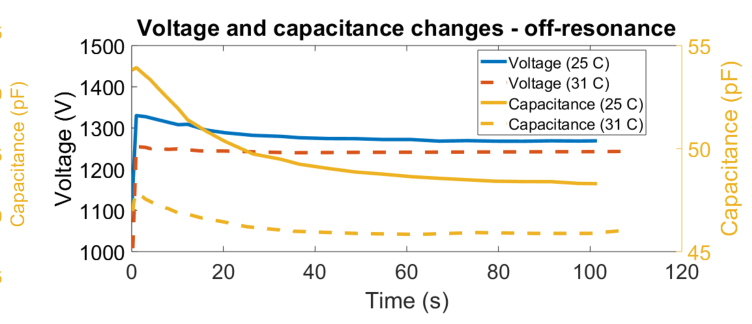
- Seconds-long latency between turn-on and glow inception
- Preheating reduces delay both on- and off-resonance
- Off-resonance, V lower with heating
- Ignition ≡ 10% of max PMT signal
- V error ~1% , 20 V; C error ~ 0.2 pF



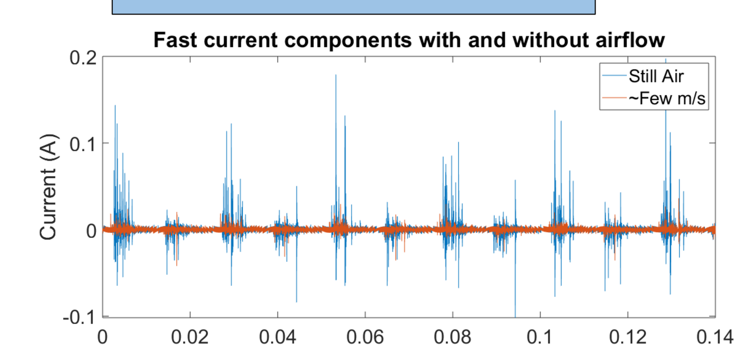



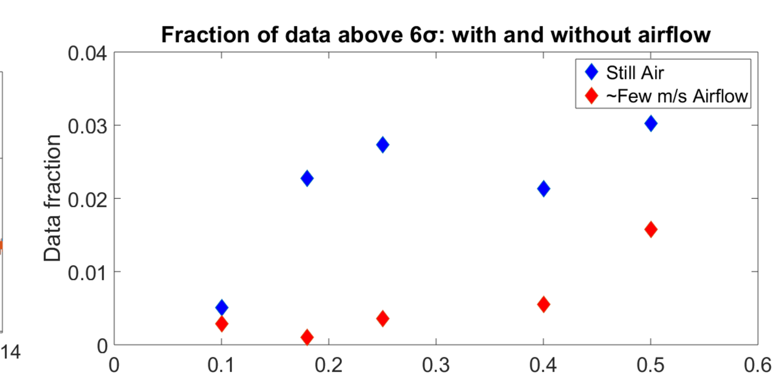



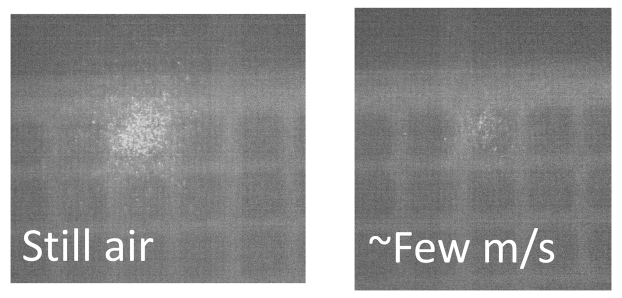



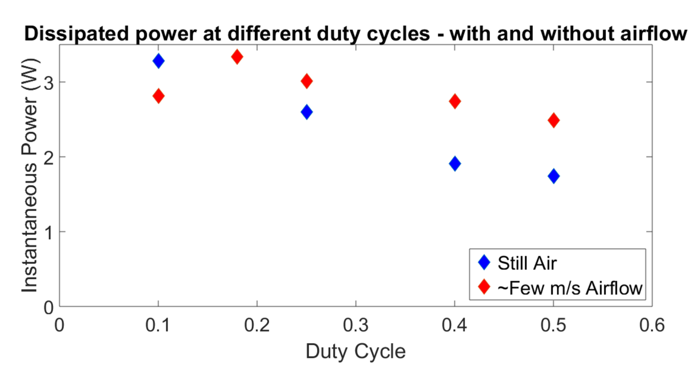

### Airflow Influence

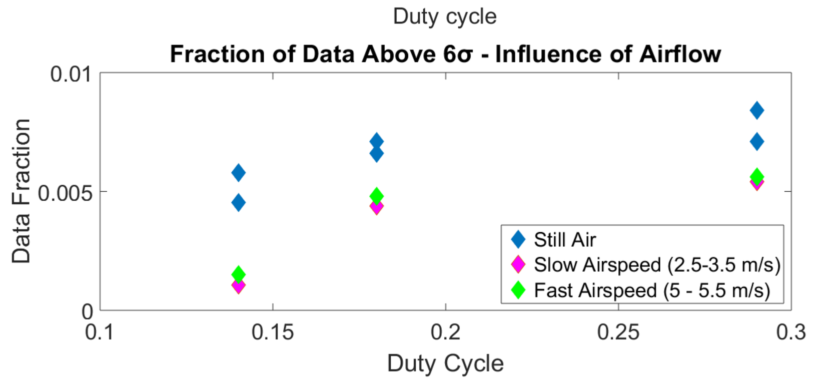
- "Spike" size decreases with airflow
- Quantify by spline-fitting data and counting data points > $6\sigma_{noise}$ from 0
- No clear trend for dissipated power
- No clear difference 2.5 m/s vs 5 m/s
- Discharge still diffuse with airflow
- Power error: ~4%




## Discussion

Glow Latency

- Possible cause: $\Delta T \rightarrow \Delta C \rightarrow (V \uparrow)$ (from resonance effect)
  - Capacitance decreases with pre-heating
  - Preheating: $V \uparrow$ on-resonance, $V \downarrow$ off-resonance
  - Ignition faster on- and off-resonance; reject explanation

| Measurement | Res, No Heat | Res, Preheated | Off-res, No Heat | Off-Res, Preheated |
|---|---|---|---|---|
| Ignition Time (s) | 12 | <2 | 12 | 2 |
| Ignition Voltage (RMS, V) | 1210 ± 20 | 1270 ± 20 | 1310 ± 20 | 1250 ± 20 |
| Final Voltage (RMS, V) | 1470 ± 20 | 1470 ± 20 | 1270 ± 20 | 1240 ± 20 |
| Ignition Capacitance (pF) | 44.6 ± 0.2 | 42.7 ± 0.2 | 51.4 ± 0.2 | 47.7 ± 0.2 |
| Final Capacitance (pF) | 39.7 ± 0.2 | 39.1 ± 0.2 | 48.3 ± 0.2 | 45.9 ± 0.2 |

Note: V-errors estimated from 1% fluctuation, C-errors from fitting

- Possible cause: $(T_{gas}\uparrow) \rightarrow (n_0 \downarrow) \rightarrow (\frac{E}{n_0}\uparrow) \rightarrow (\alpha \uparrow)$
  - $\Delta T < 10°\ C \rightarrow \frac{\Delta T}{T_{room}} < \frac{10\ K}{298\ K} \approx 3\% \rightarrow \left|\frac{\Delta n}{n_0}\right| \leq 3\%$
  - As $\alpha = n_0 * f\left(\frac{E}{n_0}\right)$ [11], f increasing, $\Delta V \downarrow$ offsets $\Delta n \downarrow$ off-res
  - $\left|\frac{\Delta V_{heat}}{V_{non}}\right| = \left|\frac{-60\ V}{1310\ V}\right| \approx 5\% > 3\%, \Delta V_{heat} < 0$; expect $\alpha_h \leq \alpha_c$
- Possible cause: $\Delta T \rightarrow$ water desorption from Kapton
  - Known [12] that water forms monolayer on Kapton
  - [13] $E_{adh} = \gamma_{water} * (1 + \cos(\theta)), \gamma_{water} = 72\frac{mJ}{m^2}$ = surf. energy, [14] $\theta = 75°$ = Water-Kapton contact angle
  - $E_{adh} \approx 91\frac{mJ}{m^2}$; water diam. $3 \times 10^{-10}\ m$, $E_{adh} \sim 50\ meV$; $\Delta E_{heat} \sim k\Delta T \sim$ 1meV,
  - $\Delta E_{heat}$ not vanishing compared to $E_{adh}$; cannot rule out effect

Airflow

- Possible causes:
  - Changing device temperature
  - Changing metastable density - fewer seed electrons [15]
  - Max speed: 5 m/s, discharge duration: 100 ns, AC period: 25 µs
  - 0.5 µm and 125 µm movement, <0.1 % and <20% of cavity size
  - min speed 2 m/s, duty cycle 10 ms => 2 cm ≈ device size
  - Airflows could eliminate metastable build-up across duty cycles

## Summary and Future Work

- When this DBD device is operated in air at low duty cycles, temperature and external airflows should be considered
- Future work:
  - Conduct glow latency experiments in dry air
  - Find regime where airflow influence changes with speed

## Acknowledgements

- This work was made possible by funding from the Department of Energy Workforce Development for Teachers and Scientists (WDTS) for the Summer Undergraduate Laboratory Internship (SULI) program. This work is supported by the US DOE Contract No. DE-AC02-09CH11466.
- The authors thank Dr. Y. Raitses (Princeton Plasma Physics Lab) for helpful discussions.

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