Investigating the operating principle of the Emisense PMTrac sensor

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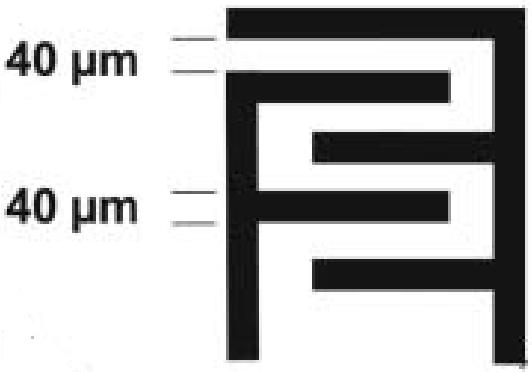
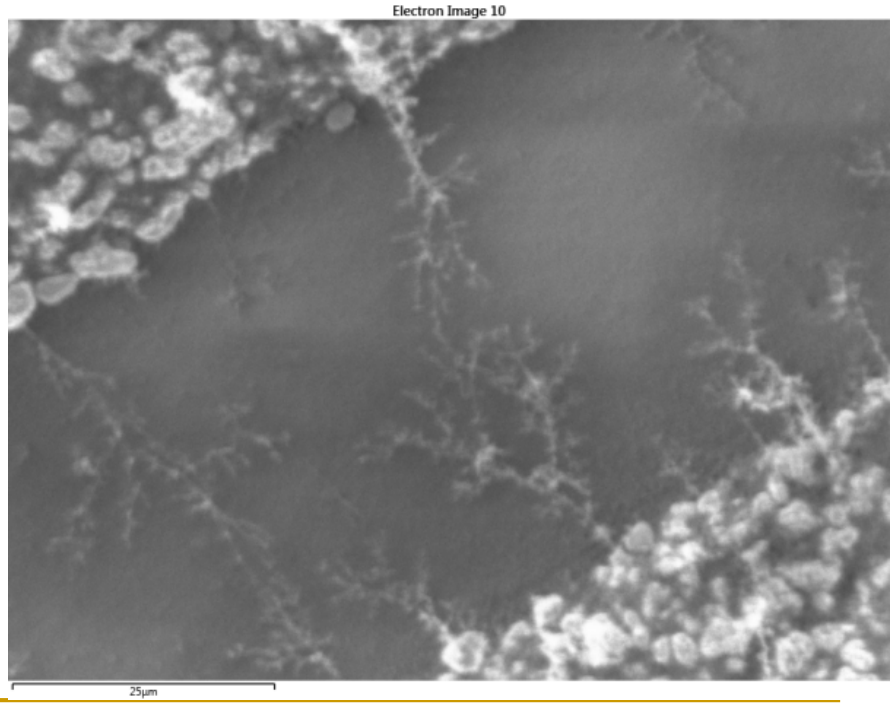
Introduction

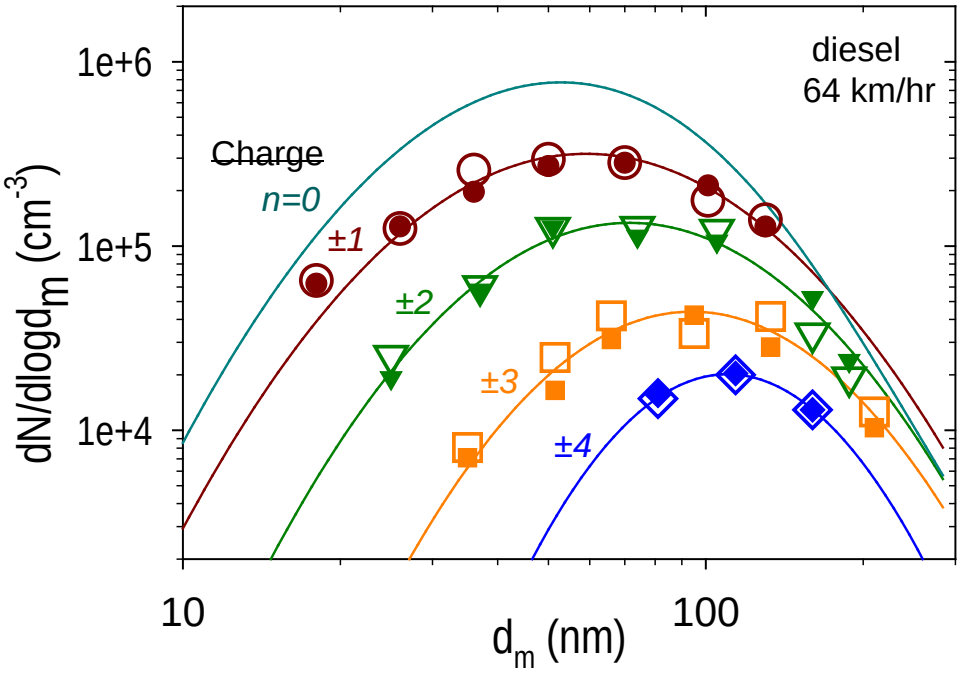
- On-board diagnostics (OBD) is required to monitor health of diesel particulate filters (DPF)
- Current method is the resistive sensor
- Many problems
  - deposition efficiency unknown
  - insufficient sensitivity
  - takes too long



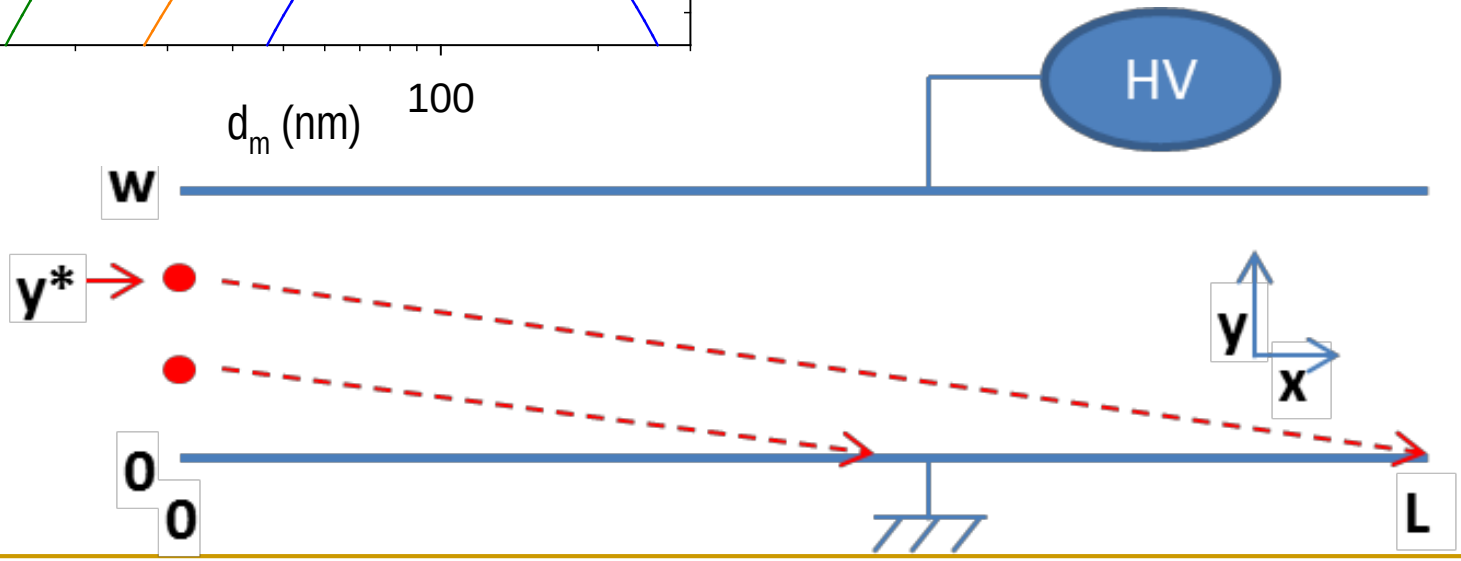
Electrode structure



Emisense PMTrac sensor – electrostatic trap



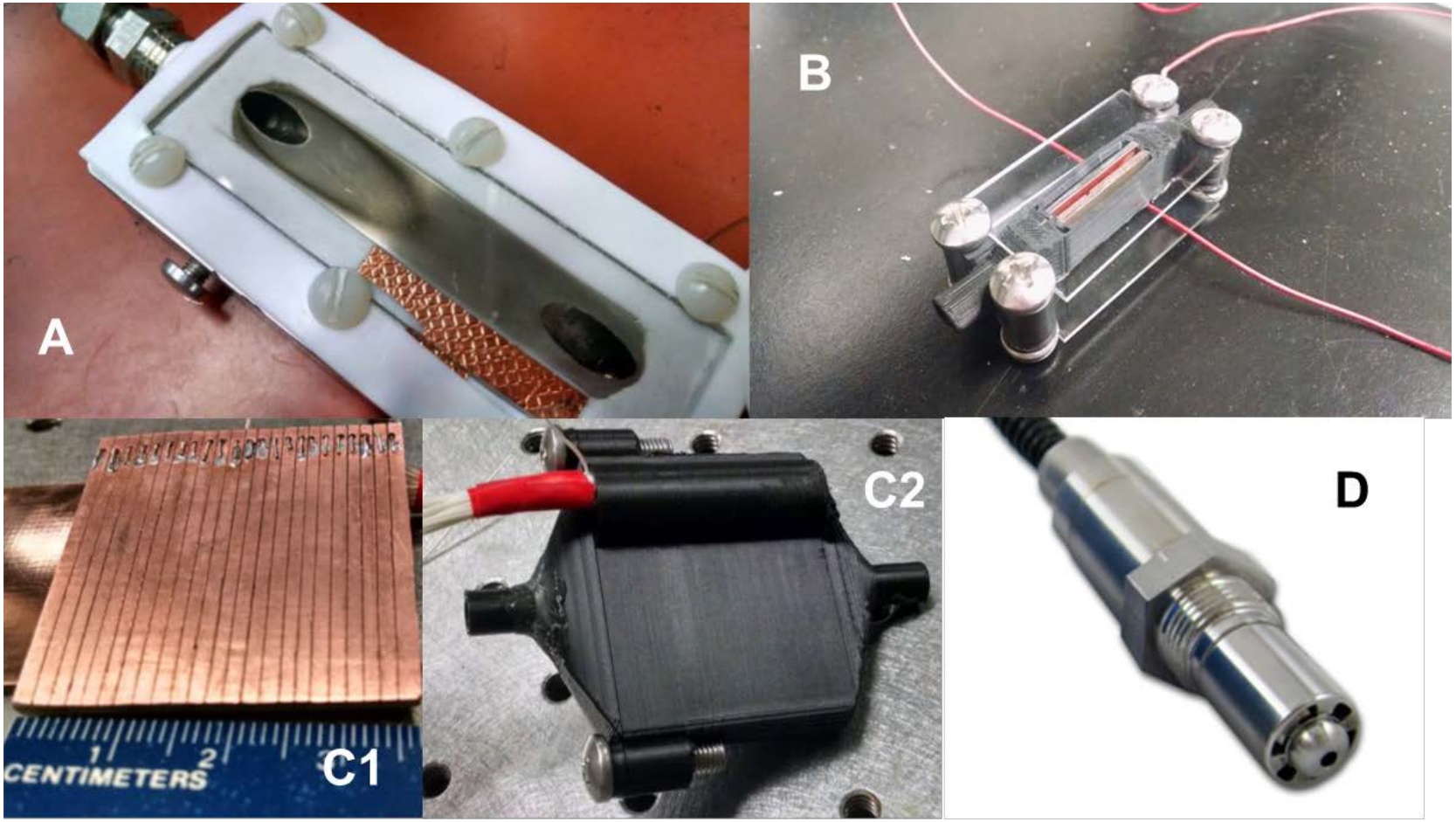
- soot is naturally charged in flame
- bipolar with approx 30% + and 30% - charges



Electrostatic traps

Top view

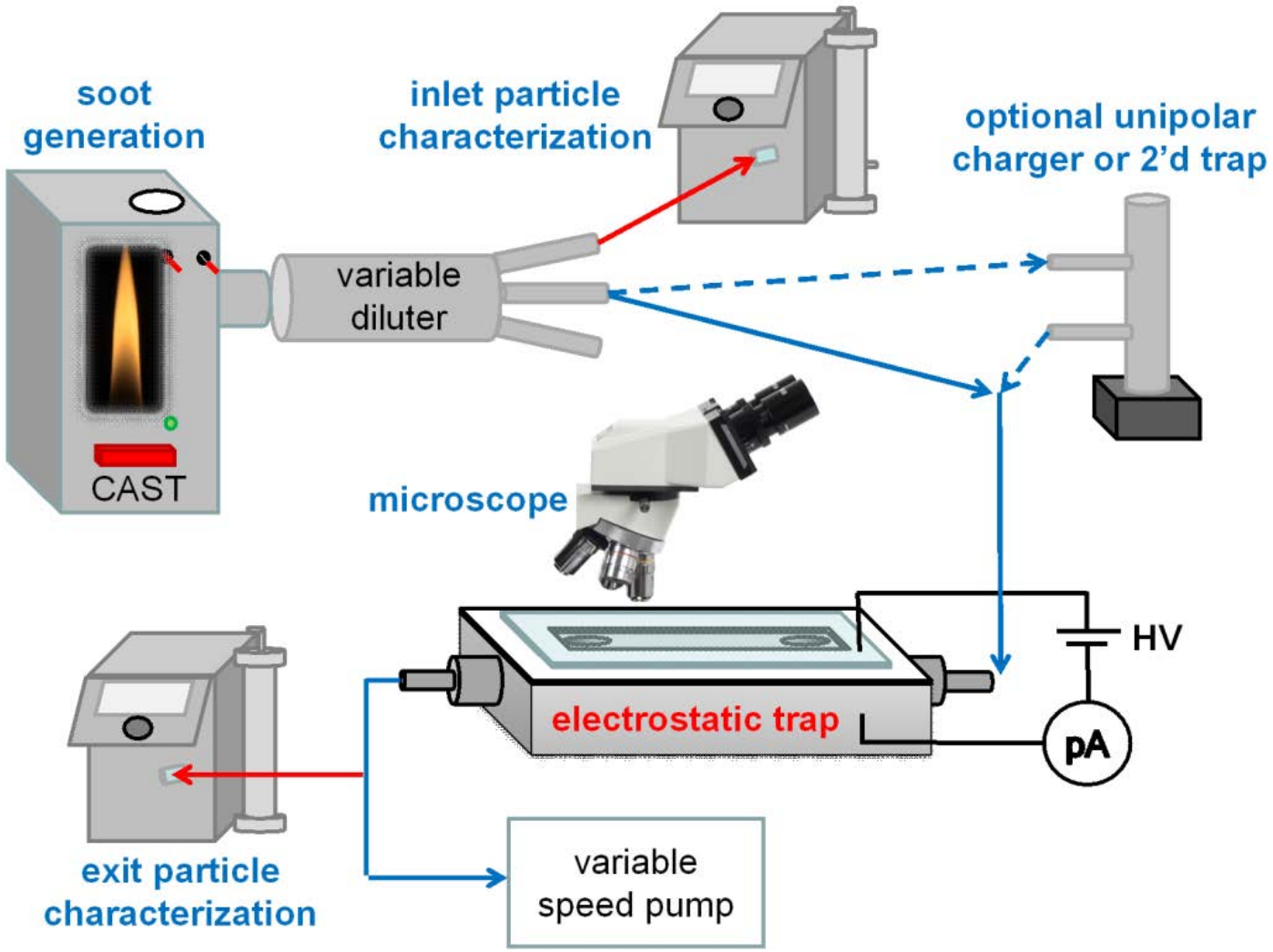
Side view



Segmented

PMTrac

Experimental setup

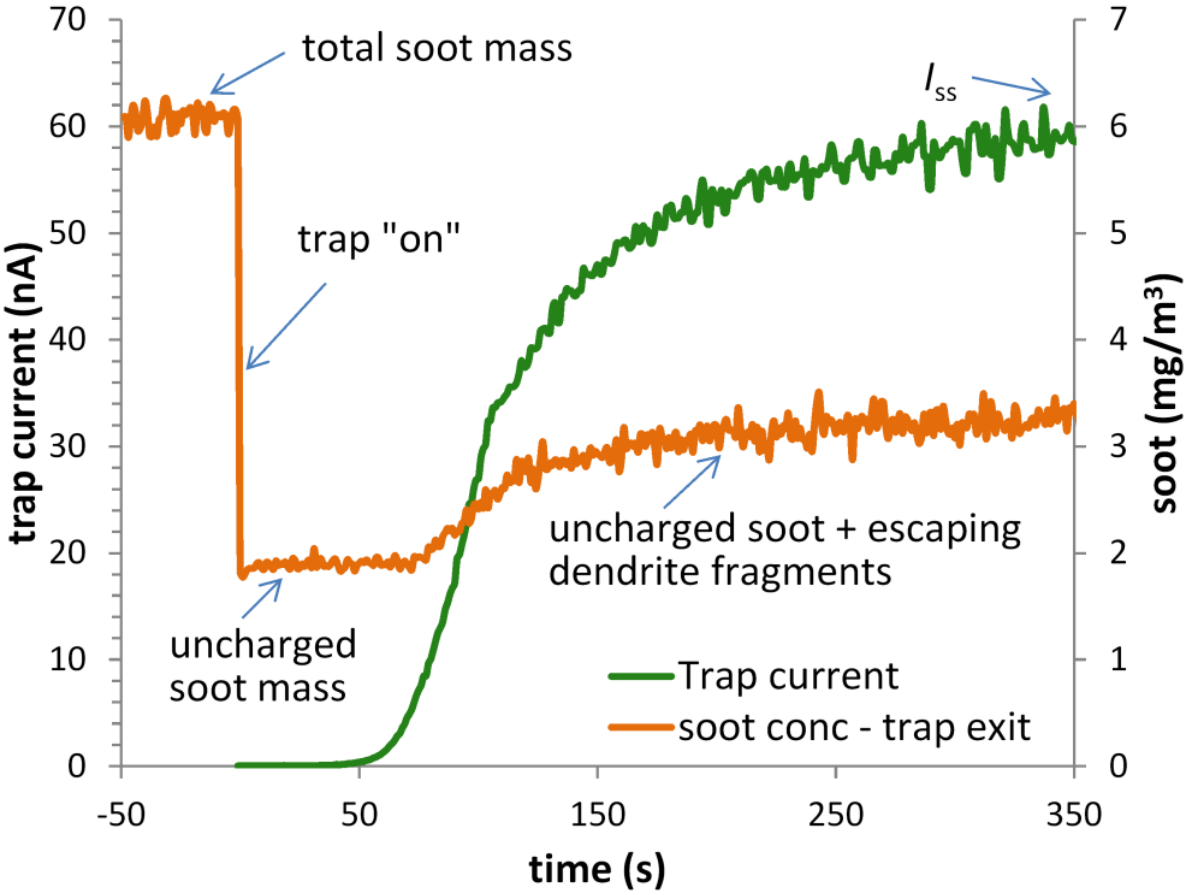


Trap current & exiting soot mass

Characteristic Behavior

- Delay period of minutes where trap current is pA
- And exit soot mass is ~1/3 of entrance value

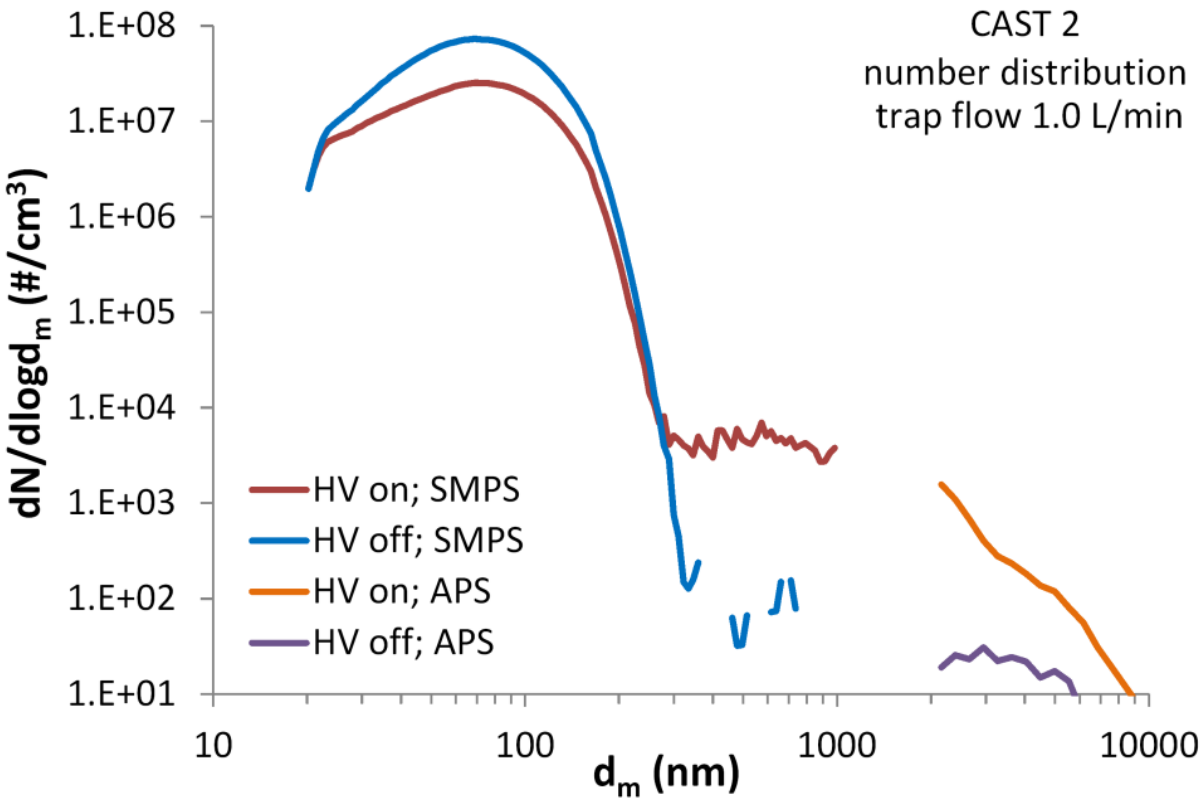
- After ~ 1 minute current rises to nA
- And exit soot mass increases



SMPS – APS size distribution of soot at trap exit

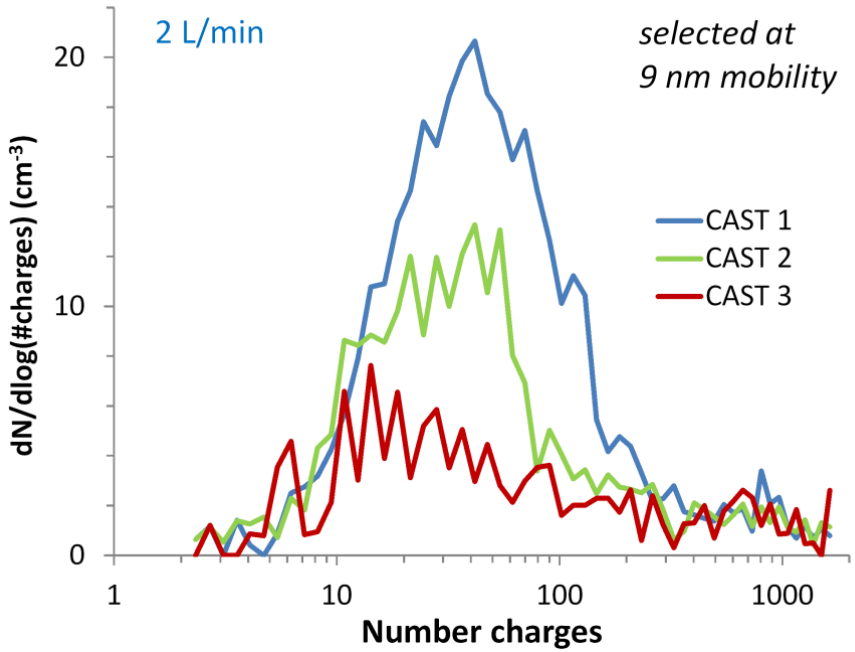
Trap on

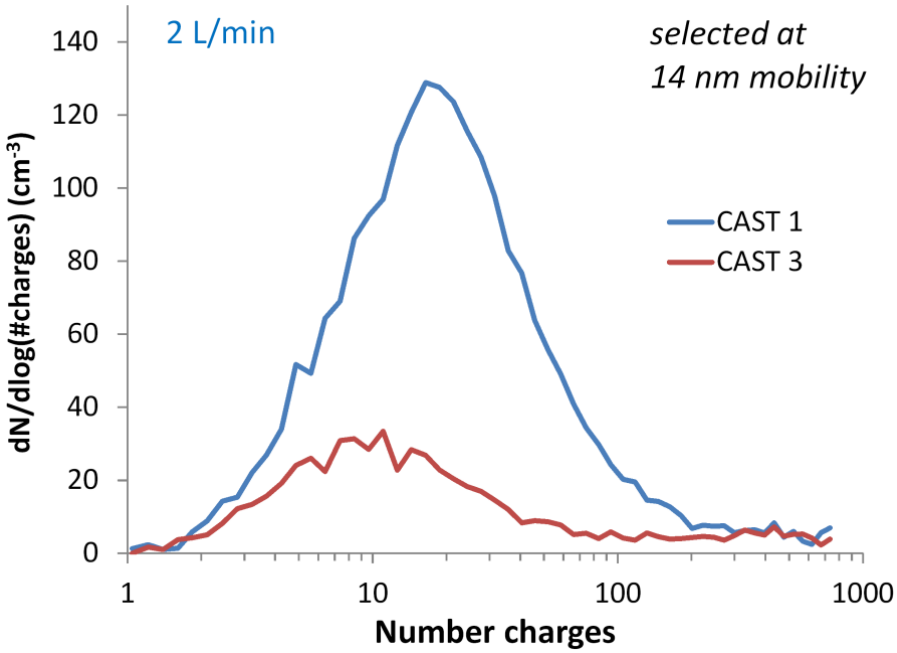
- Particle number at ~100 nm reduced with trap turned on
- Particle number at ~1000 nm increases with trap on



Tandem DMA measurement of dendrite fragment charge

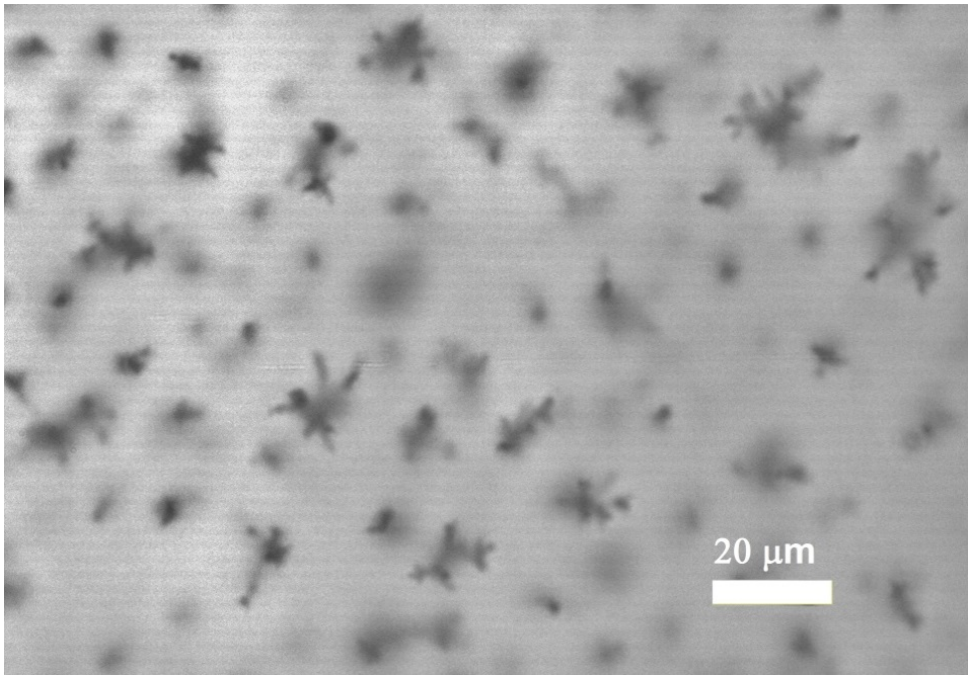
Some fragments exiting the trap have very large numbers of charges: tens to hundreds





In situ images of soot dendrites

Top view

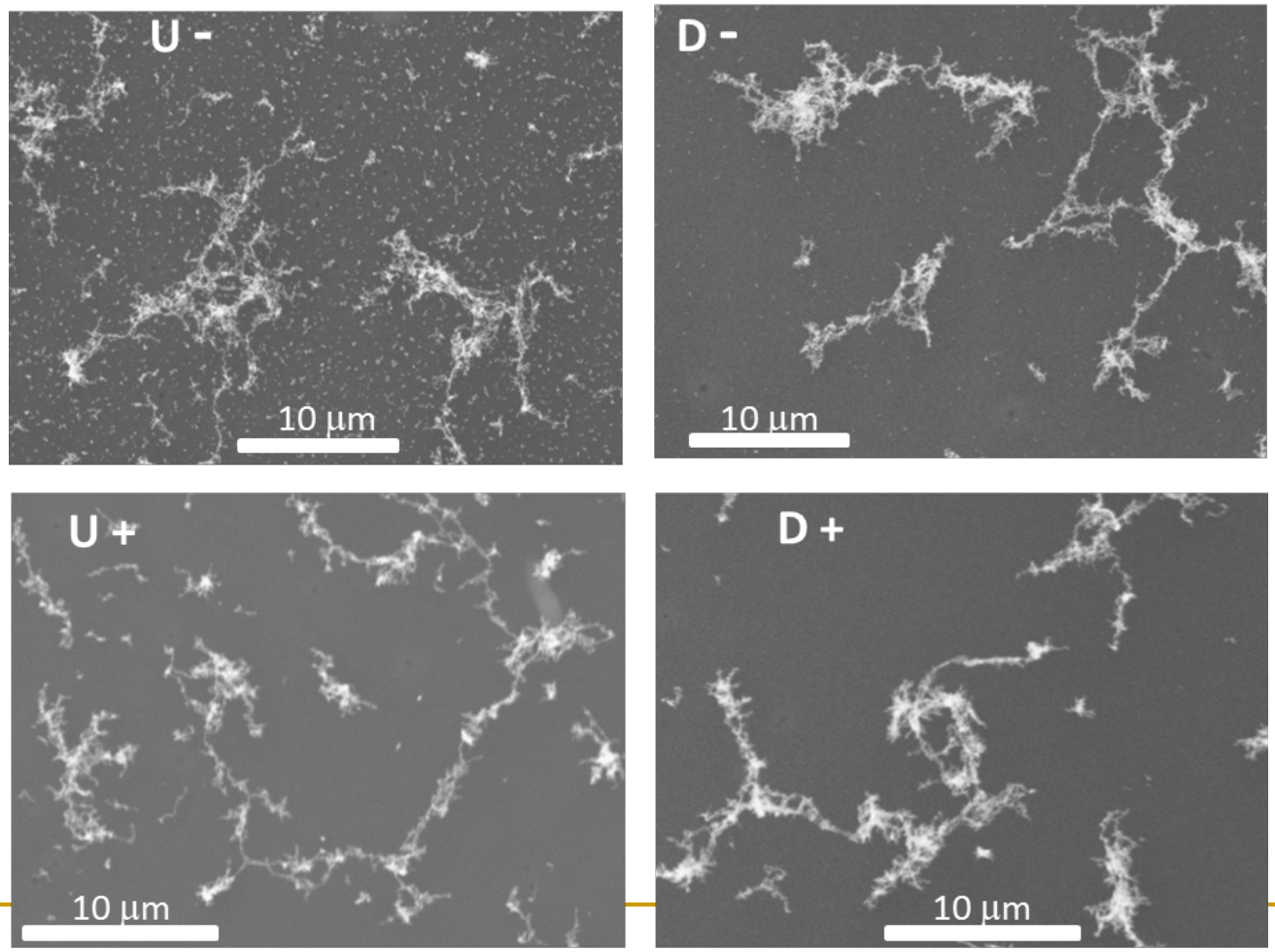


Electric field induces growth of high aspect dendritic structures.

Side view

SEM images of soot on electrodes

- Sample unipolar soot into electrostatic trap
- Soot dendrite structures found on both electrodes!
- Implies that soot is moving from one electrode to the other



Trap model

- Kinetic model for soot dendrite growth and fragmentation
- Current carried by dendrite fragments

- S = entering soot flux
- D_n = dendrite with n segments
- Br = “break-off” fragment

Dendrite growth

$$S + D_n \underset{k_s}{\rightarrow} D_{n+1}$$

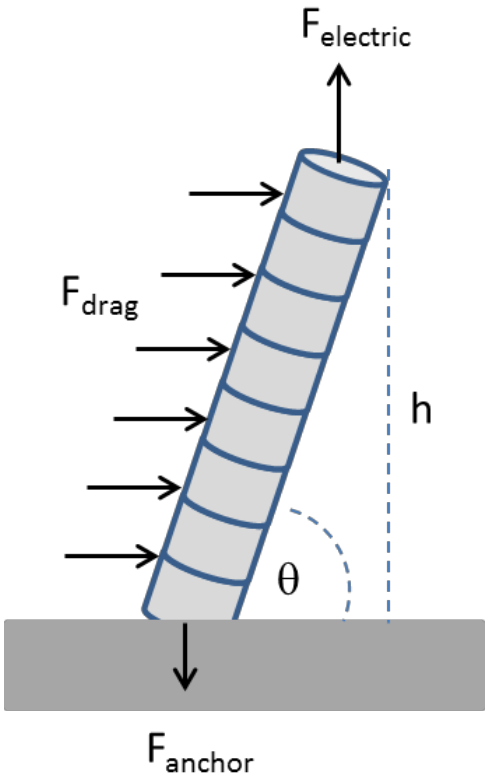
$$Br + D_n \underset{k_b}{\rightarrow} D_{n+f}$$

Dendrite fragmentation

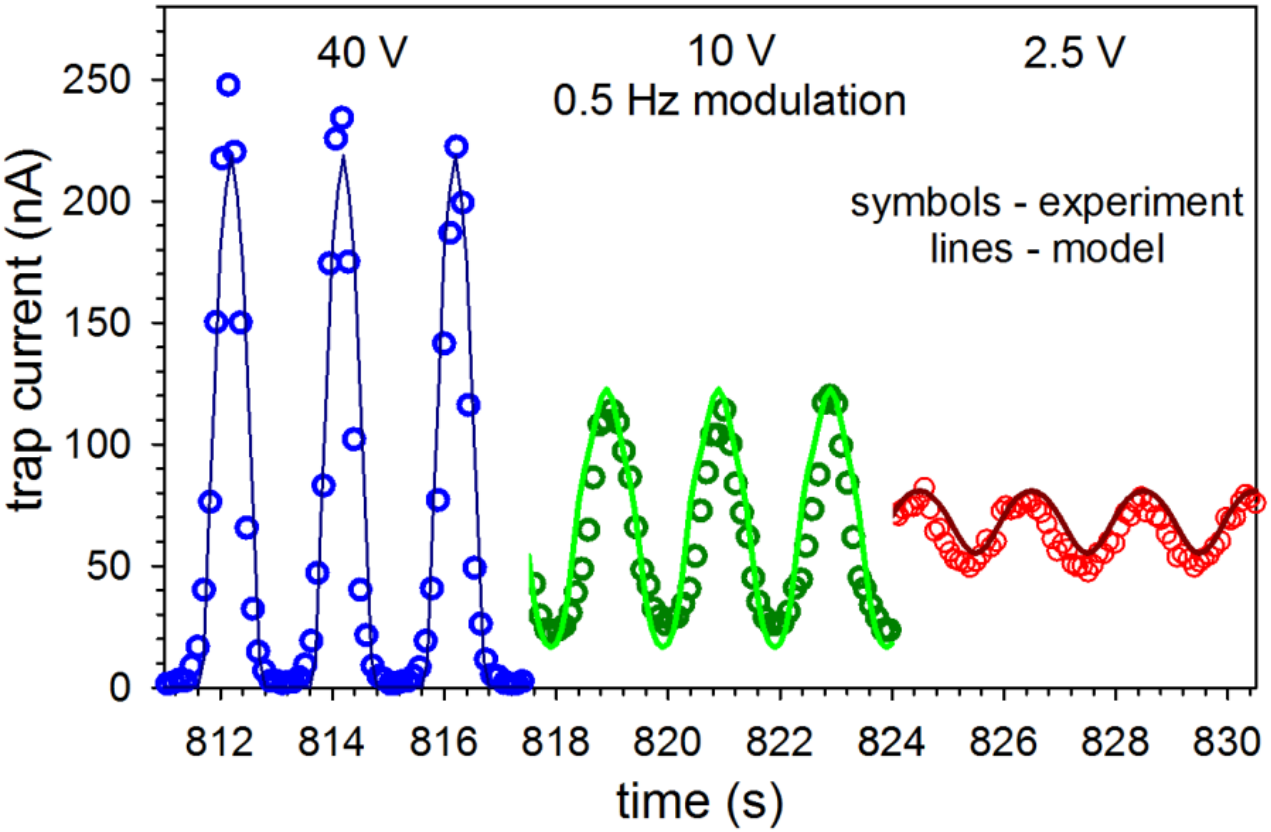
$$D_n \underset{k_F}{\rightarrow} D_{n-f} + Br \qquad (n > n^*)$$

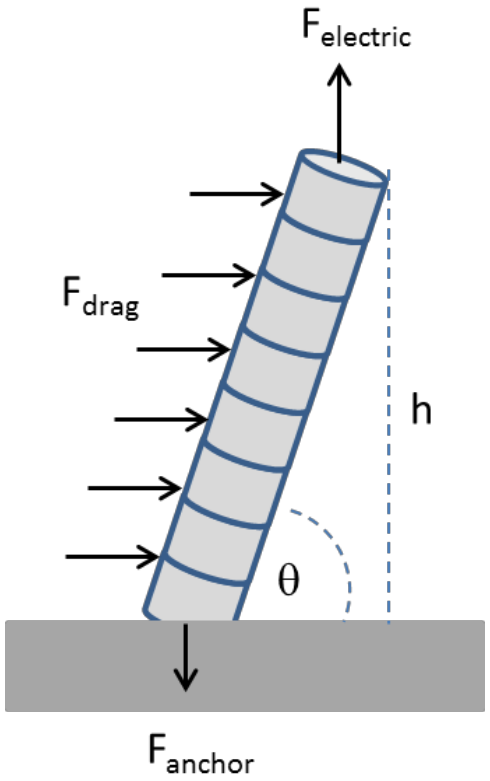
Fragment loss

$$Br \underset{k_L}{\rightarrow} exits\ trap\ or\ lost$$



Comparison of model to experiment: 1). Voltage modulation

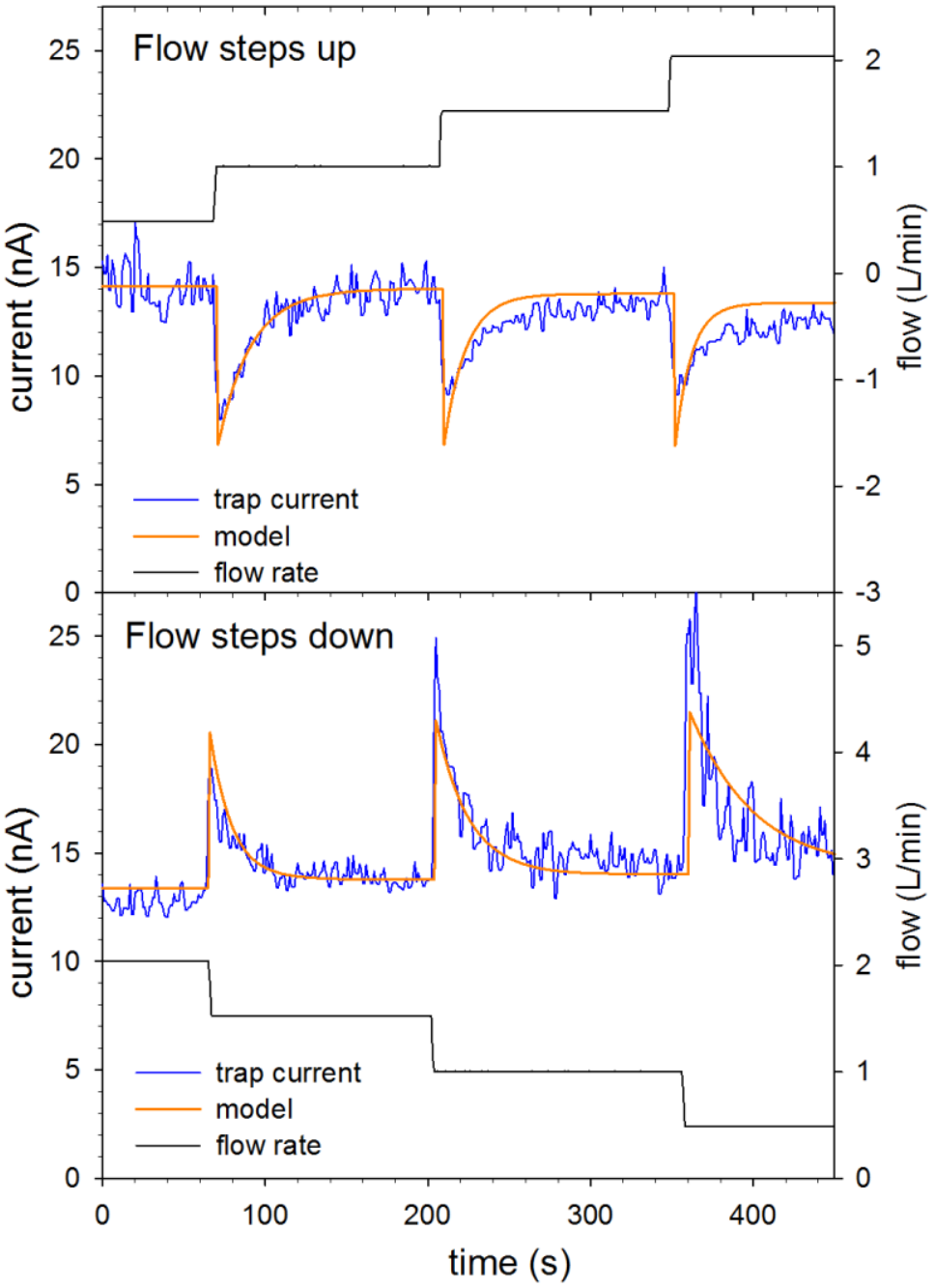




small modulations of HV, 0.25 – 4%, have a large impact on trap current, 20 - >100%

2) Flow dependence

- Steps up (down) in flow through trap cause transient under (over) shoots in trap current
- This behavior is not seen for step changes in soot concentration



Summary

- PMTrac operates on electrostatic trap principle
- Electric field causes the growth of high aspect ratio dendrites from the electrode surfaces
- As these grow, they reach a threshold height at which the dendrite fragments
- The fragment carries away a charge equivalent to or greater than the surface charge of the electrode
- The resulting “chain reaction” of growth, fragmentation, charge transport amplifies the incoming pA current carried by soot particles to nA levels.