Summary of the ANL Workshop on Unipolar Arcs

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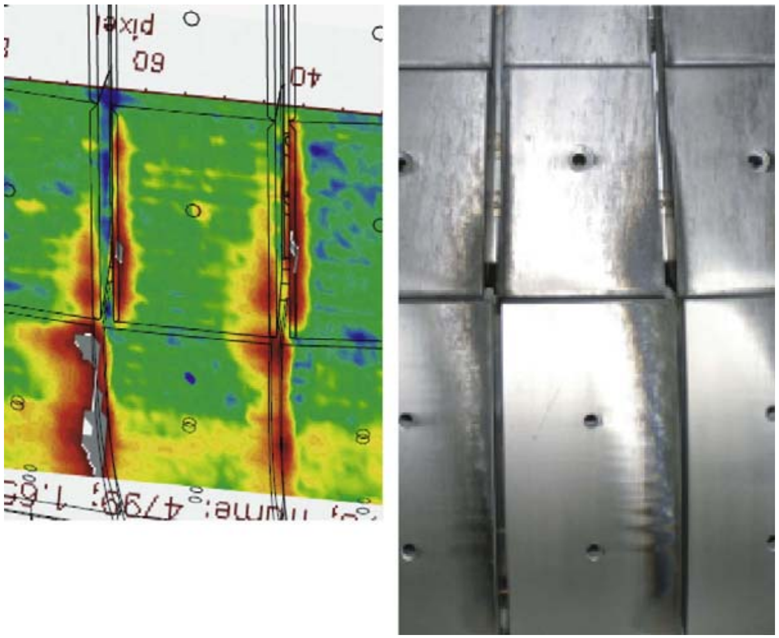
- Workshop program and presentations
- Unipolar arcs in NSTX (?), LTX, MRX
- Physics of unipolar arcs
- Possible ways to suppress arcing

Unipolar arcs can be one of major sources of impurities in fusion devices

- Unipolar arcs are short duration of < 1 msec (typically 10's μsec), current of 1- 10's A, high current density (10^{12} A/m^2) localized discharges that can occur between the plasma and a PFC.
- Studied on DITE, PLT, ISX, DOUBLETIII, ASDEX, ASDEX U.
- Plasma-exposed components show tracks, scratches or pits caused by the intense local arc erosion that are visible to the naked eye.
- The PFC material is evaporated and eroded quickly (> 1 μm) due to the significant local heating by the arc.

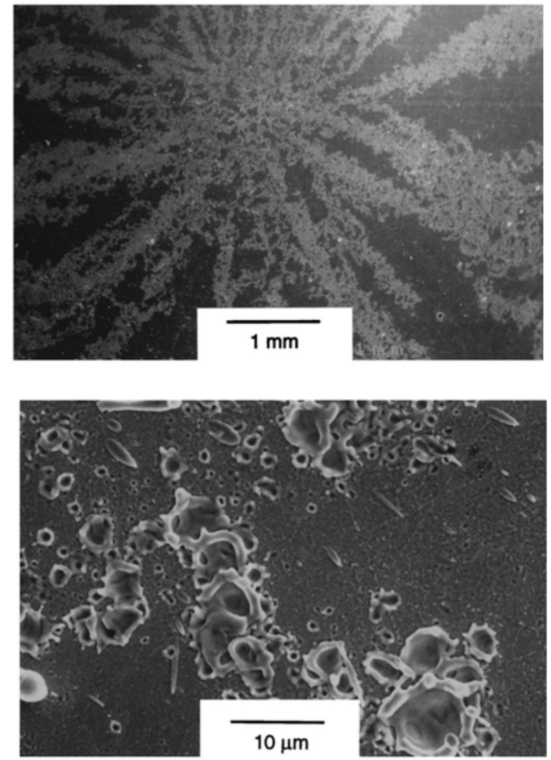
- **The metal removed from the arc tracks is sufficient to explain the metal atom concentration in the plasma: 10^{17} atoms per arc.**
- **More arcs at the initial and final stages of the discharge, prior to disruptions, ELM's etc.**

Characterization of unipolar arcs



View of the IR-camera and photo of an arc pattern of a comparable region in the inner divertor on ASDEX-Upgrade

A. Herrmann et al., J. Nucl. Materials, 2009



Arc produced erosion tracks (low and high magnification)

S. Wang and I. Borown,
Rev. Sci. Instum, 70, 1999

Workshop Motivation & Goals

• Arcing seems to limit the maximum gradients in accelerators and to impose additional restrictions on plasma-wall interaction in fusion devices, among other things.

• The goal of this meeting was to try to look at the problem of surface damage due to arcing from a number of different directions, and look toward a program that addresses the problems in an efficient way.

• The idea was also to bring together people in different fields to discuss whether there was any common ground in a variety of different approaches to arcing studies. **A discussion was started**.

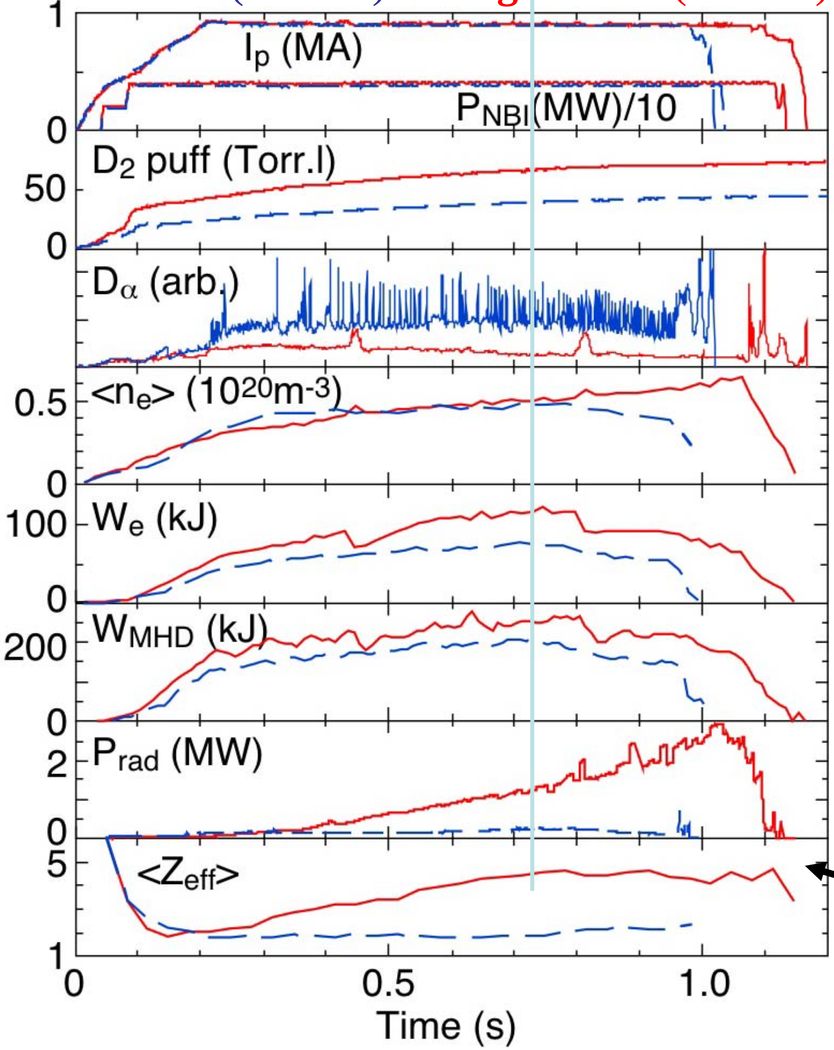
Workshop Program, 1/29/2010

Chairs: Jim Norem (ANL), Ahmed Hassanein (Perdue) and Zeke Insepov (ANL)

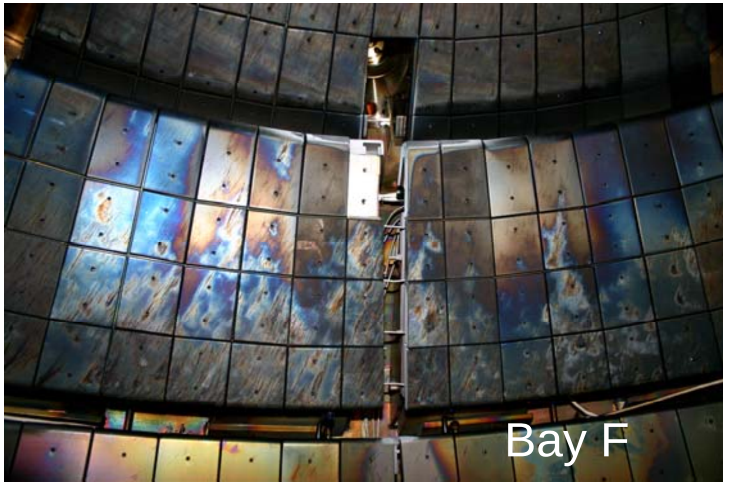
	Welcome (Conference Center: 08:30 - 09:00)
09:00	**Cathodic Arcs-A.Anders (LBL)** (Conference Center: 09:00 - 09:30)
	Unipolar Arcs-C. Castano (Missouri ST) (Conference Center: 09:30 - 10:00)
10:00	**non debye plasma-G. Norman (JIHT Moscow)** (Conference Center: 10:00 - 10:30)
	Break (Conference Center: 10:30 - 11:00)
11:00	**Arcs in accelerator structres-J. Norem (ANL)** (Conference Center: 11:00 - 11:20)
	ripples and cracks-Z. Insepov (ANL) (Conference Center: 11:20 - 11:40)
	Pits in e beam welding-L. Cooley(Fermilab) (Conference Center: 11:40 - 12:00)
12:00	**Lunch Break** (Cefeteria: 12:00 - 13:00)
13:00	**Plasma/materials interactions in the Fusion Program-J. Brooks (Purdue)** (Conference Center: 13:00 - 13:20)
	Demonstration of unipolar arcing under fusion relevant conditions-S. Kajita (Nagoya) (Conference Center: 13:30 - 13:50)
14:00	**Unipolar arc examples-Y. Raitses (PPPL)** (Conference Center: 13:50 - 14:10)
	Breakdown issues in antenna structures in Fusion research-J. Caughman (ORNL) (Conference Center: 14:10 - 14:30)
	Break (Conference Center: 14:30 - 15:00)
15:00	**On temperature bifurcation of beryllium and lithium plasma facing components-R. Smirnov (UCSD)** (Conference Center: 15:00 - 15:20)
	techniques and numberical methods-S. Veitzer (Tech X) (Conference Center: 15:20 - 15:40)
	arc simulation using Aleph, a DSMC/PIC code-P. Crozier (Sandia) (Conference Center: 15:40 - 16:00)
16:00	**Discussion** (Conference Center: 16:00 - 17:00)

Possible signatures of unipolar arcs on NSTX?

No lithium (129239) **260mg lithium** (129245)



M. Bell's PPPL colloquium, January 2010



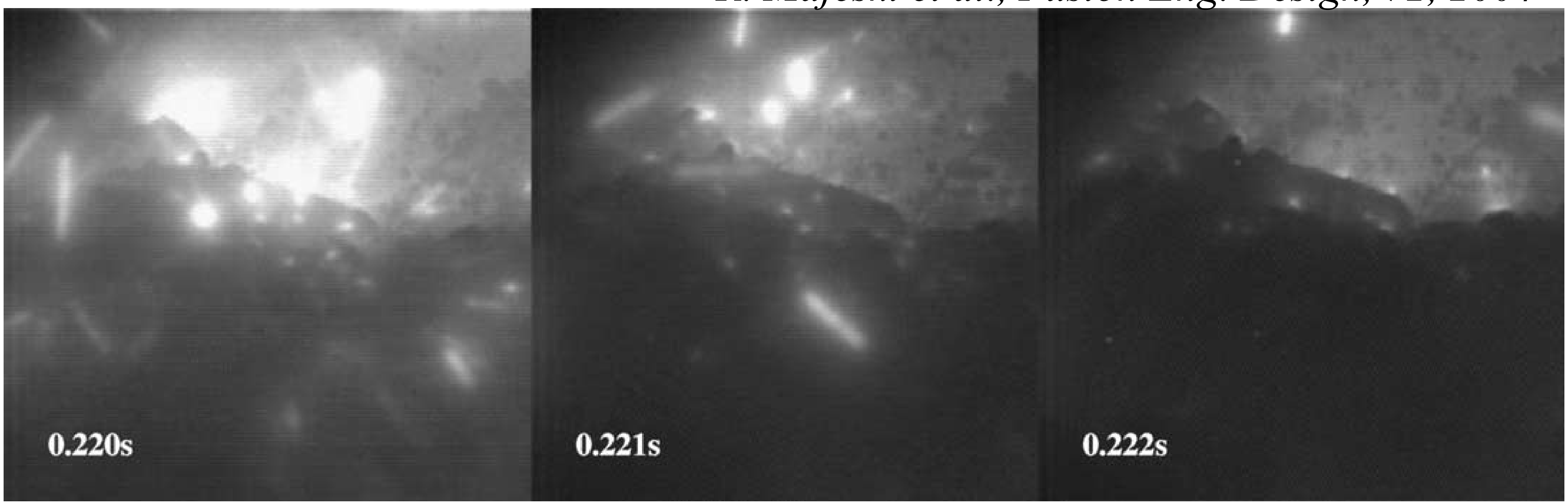
Impurity accumulation increases radiated power: source not identified

H. Kugel, B. LeBlanc, R.E. Bell, C. Skinner

Unipolar arcs in liquid lithium limiters in CDX-U

- Unipolar arcing occurred during initial operation when the surface of the lithium was oxidized (tray was loaded with solid lithium)
- Arcing decreased after hundreds of discharges

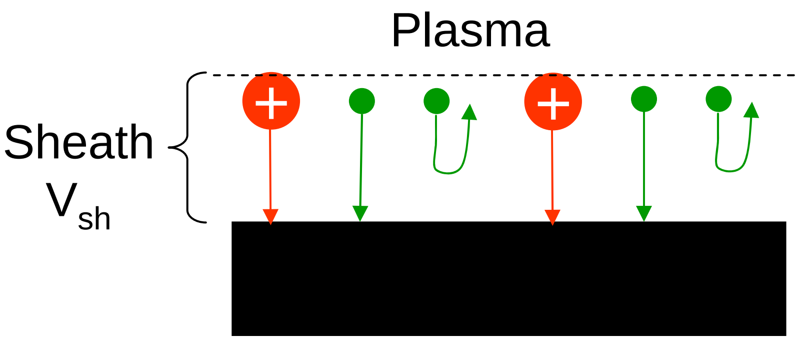
R. Majeski et al., Fusion Eng. Design, 72, 2004



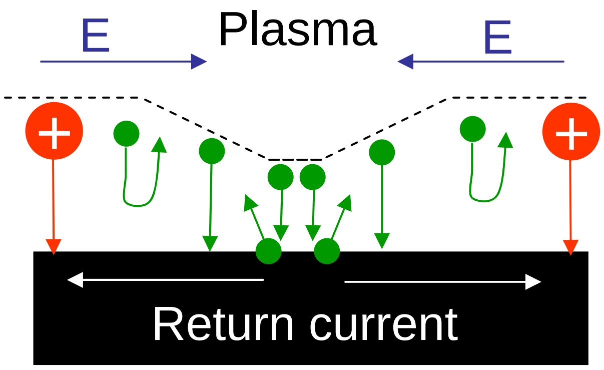
- **No arcing with clean, molten lithium (injected on a hot tray, argon glow to clean, agitation with e-beam to remove oxides)**

R. Majeski and R. Kaita

Physics of unipolar arcs (no B-field)



Dielectric wall:
$J_i = J_e$, everywhere
$V_{sh} = T_e \mathrm{Ln}(M/2\pi m)^{0.5}$



Conductive wall with electron emitting (δ) spot

Global floating condition:
$\int_S [J_e(1-\delta)-J_i]\cdot dS = 0$,

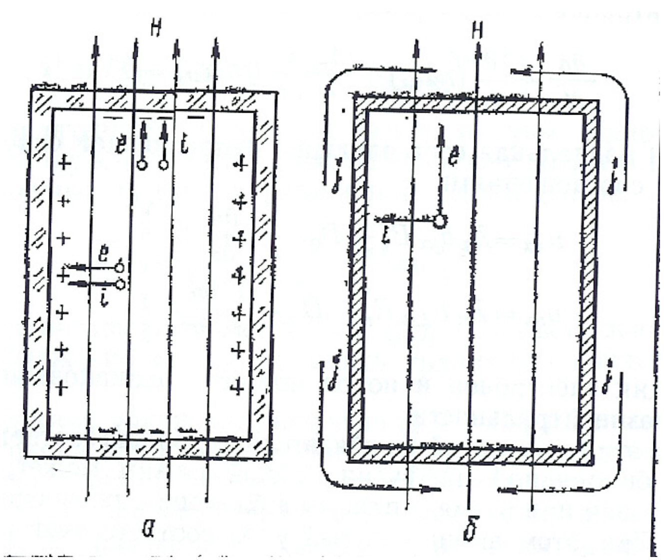
Arcing can occur if

- -The sheath potential drop, V_{sh} exceeds the arc voltage (from experiment ~ for metal vapor arcs, 10-50 V, lower for alkali metal arcs)
- -The arc current is sufficient larger to form the spot (from experiment)
- - Source of breakdown or emission source (field, thermionic, evaporation)

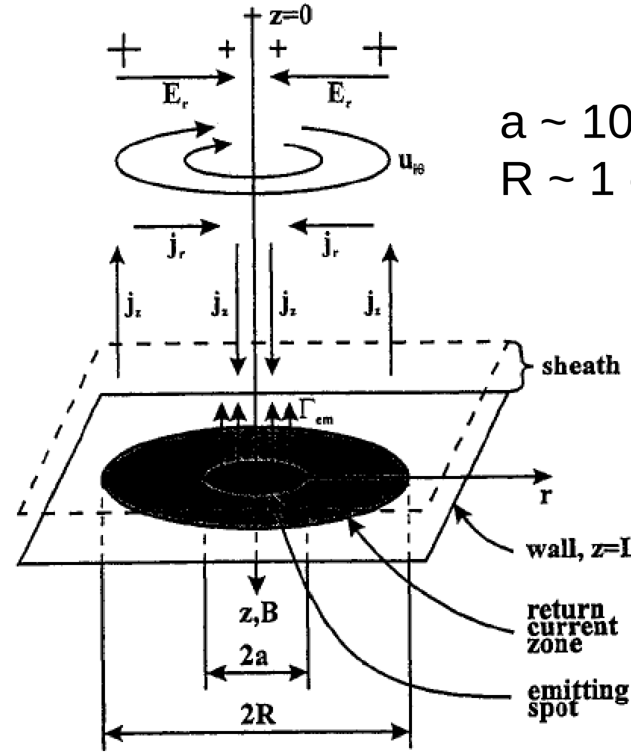
A. E. Robson and P. C. Thonemann, Proc. Phys. Soc. 1958
A. V. Nedospasov and V. G. Petrov, J. Nucl. Materials, 93, 1980

Short-circuit effect and unipolar arcs in magnetic field

In a chamber with conducting walls electrons can escape along magnetic field and ion can diffuse across magnetic field



A. Simon, Phys. Rev. 98, 317 (1955).



a ~ 10 -10^2 μm
R ~ 1 cm

The radial current is caused by the perpendicular ion viscosity and the longitudinal current is determined by the classical conductivity.

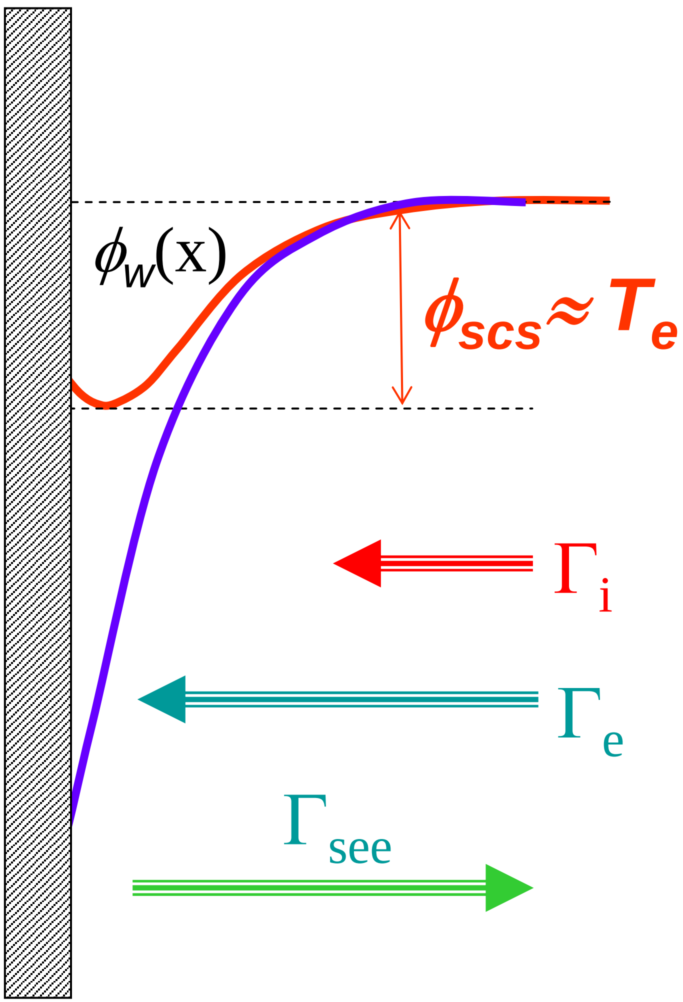
Rozhanskiy et al., Nuclear Fusion. 36, 1996

Hot spot formation may initiate and sustain unipolar arcs

- Formation of hot spots on a first wall surface can result in a strong impurity and dust ejection into plasma and even cause discharge termination *[Tsitrone et al., NF (2009), Hollmann et al., RSI (2003); Takenaga et al., JNM (2005), K. Saito et al., JNM (2007)]*
- Hot spot formation can be related to
  - Thermionic emission
  - Hydrogen desorption
  - Thermal evaporation

IR imaging of the limiter sector during the DITS campaign [Tsitrone et al., Nucl. Fusion 49 (2009) 075011]

Electron emission from the wall can significantly reduce the sheath potential



$$\phi_w \approx \frac{kT_e}{e} \ln\left((1-\gamma)\left(\sqrt{\frac{M_{ion}}{2\pi m_e}} \right) \right)$$

When $\gamma = 0,\ \phi_w = 5.27\, T_e$ (for Xenon)

When $\gamma\left(T_e^{cr}\right) = \gamma_{cr} \approx 1 \rightarrow \phi_w^{scs} \approx T_e$

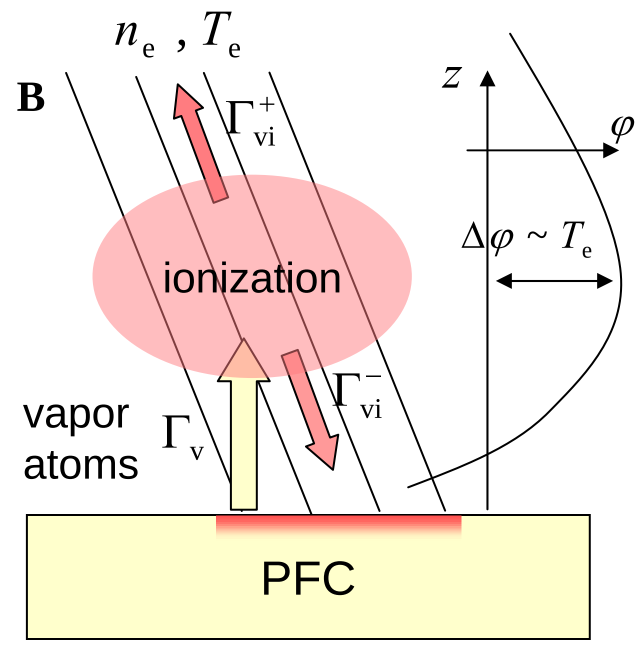
Space-Charge Limited Sheath

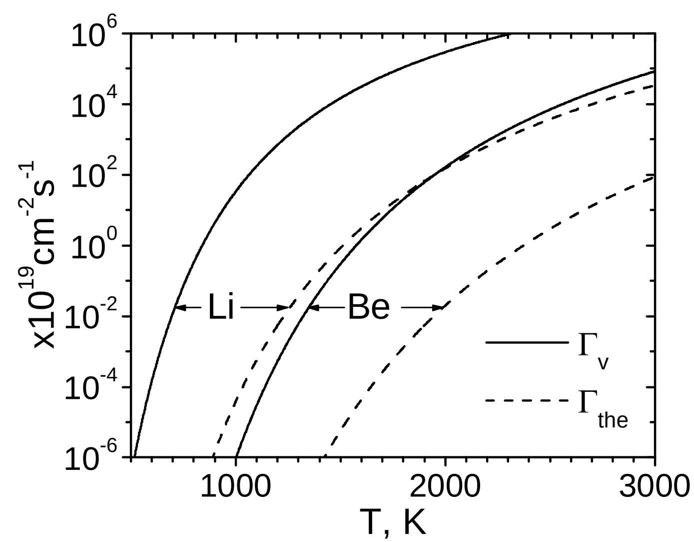
Hobbs and Wesson, 1967

With SCL sheath, wall acts as a very effective heat sink for plasma

Overheating of Evaporating Surface

- The vapor atoms are ionized in the vicinity of the PFC that increases local plasma density.
- Part of ionized vapor returns to the PFC due to acceleration in the ambipolar potential
- Returning vapor ions increase heat flux to the surface that leads to further increase of the surface vaporization and eventually to overheating
- Secondary electron emission can reduce the threshold for overheating
- Surface overheating may be a potential threat to Liquid Lithium Divertor (needed a good heat removal from tray)





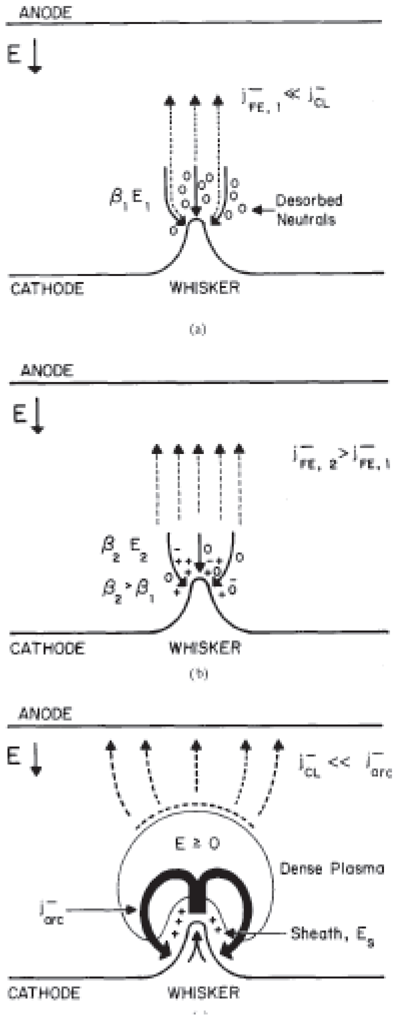
Smirnov, Krasheninnikov, Pigarov, Workshop 2010
Phys. Plasmas 16, 2009

Field emission enhancement

a) Field emission from protrusions

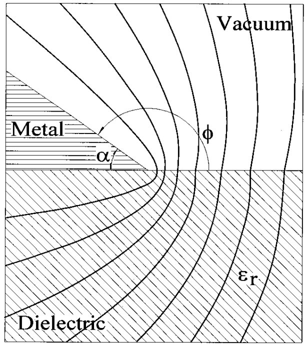
Surface breakdown is initiated by the ionization of desorbed contaminants by field-emitted electrons.

Schwirzke, IEEE TPS,19, 1991



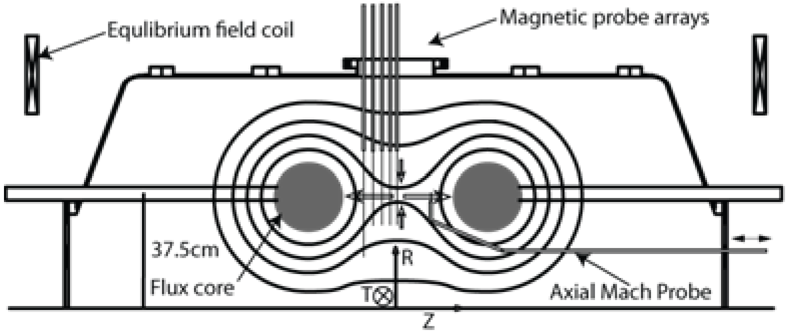
b) Triple-point electron emission

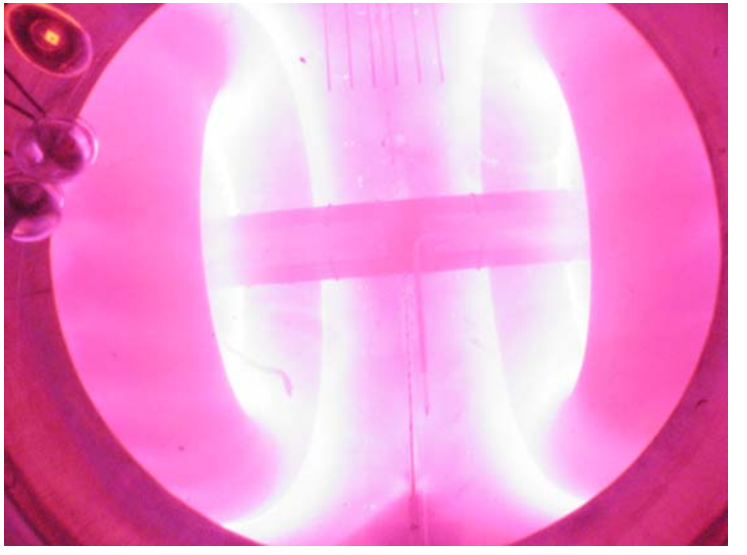
$\beta \approx (\varepsilon_r/2)^{0.5}$

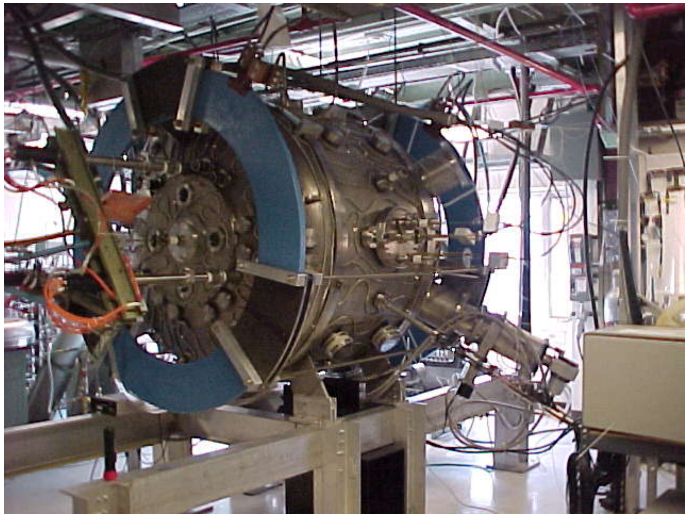


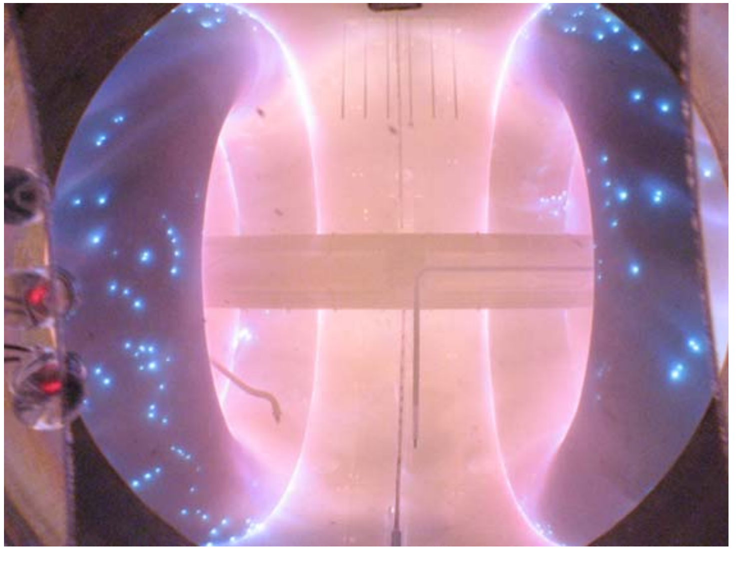
c) Malter effect - charging of dielectric (oxide layer) by electron flow and SEE:
1 μm charged to 3 MV/cm by J×t = 2.4 10^{-6} A s/cm^2

Unipolar arcs in MRX









M. Yamada, H. Ji, E. Oz

Methods of reducing arcing

- Right choice of material and material preparation (e.g. heavier arcs on Stainless Steel than on Graphite or W)
- Conditioning to remove dielectric coatings and polish surface (Initial arcing rate is much worse than the rate after many discharges)
- Segmentation of the PFC to minimize the current collected outside the arc spot and thereby to prevent the transition of the short circuit current to the arc mode ($J < J_{arc}$).
- To reduce the plasma density or electron temperature at the plasma edge
- To provide a good heat conduction of the PFC or tray with Li to prevent overheating
- Active rf-type methods (to obstruct the arc current path)

Possible unipolar arc experiment on NSTX

Key objectives:

1) to find out if the arcing is the source of metal and carbon impurities and how it depends on the presence of Lithium.
2) to develop active and passive methods of arc prevention in the presence of Lithium.

• Can utilize the existing on NSTX baffled probes in SOL or Biased Electrode or Langmuir probe array on LLD.

• Model by Rozhansky et al., Nucl. Fusion, 39 1999.