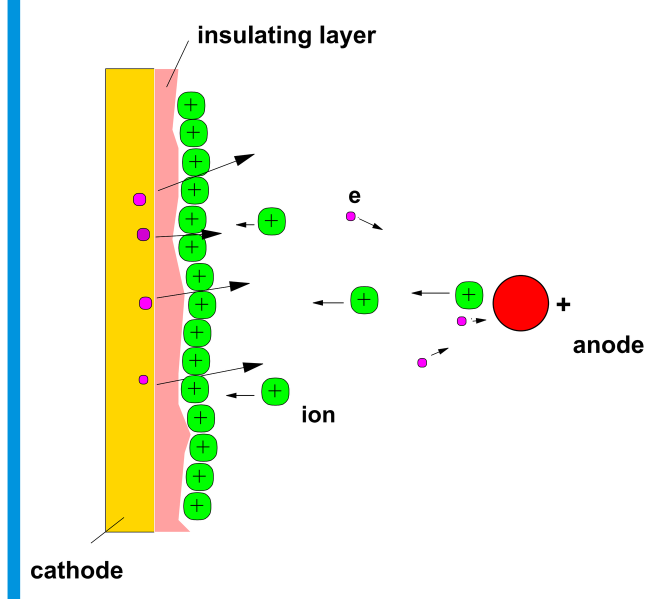
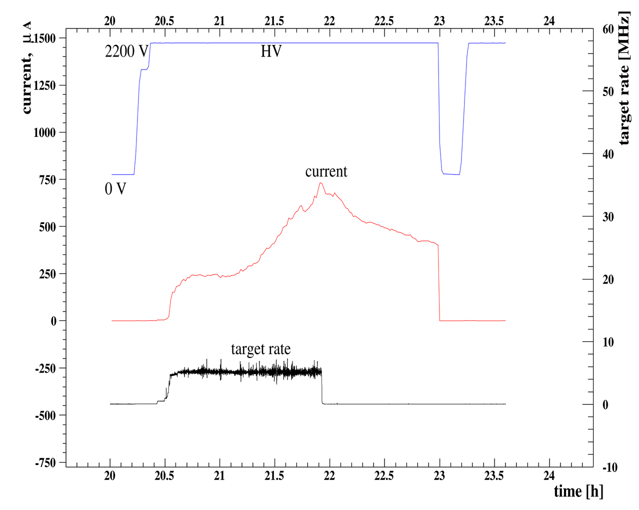
Observations on Cathode Aging (Malter-Effect) in Honeycomb Drift Chambers under High Irradiation

Details of Aging Test



Model of Malter-effect

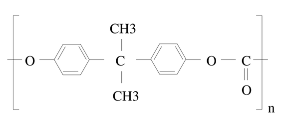
Lab. test or result from exp.:	prototype test under exp. conditions, Lab.tests
Name of the detector :	HERA-B Outer Tracker
Signif. degradation of performance:	persistent Malter currents
Most critical change:	fast reexcitation after first occurence of Malter-effect
Anode wire materialr:	25 µm Au-coated W
Cathode material:	uncoated conductive polycarbonat (POKALON-C)
Electric field on anode wire:	340 kV/cm
Electric field near the cathode:	1.7 kV/cm
Particle rate (in Hz/cm):	up to $4{\cdot}10^5$
Anode current (in nA/cm):	up to 10^3
HV applied:	2250 V
Gain (per primary electron):	$2.5{\cdot}10^4$
Type of radiation (eg: beam particle, etc.):	hadrons, electrons, X-rays
No. of primary electrons per ion. event:	$10^2...10^4$
Approximate total charge dose (in C/cm):	4 (X-rays), 10^{-3} (hadrons)
Gas composition (including additives):	CF_4/CH_4, 80/20
Gas flow rate (in detector volumes/hour):	1
Gas flow condition:	open honeycomb cells in gas-box
Gas impurities:	not analyzed
Gas pressure:	1 bar
Length and material of gas tubing:	1 to several meters; material copper, Teflon, later stainless steel
Materials in the gas system:	Noryl, Araldite AW106+hardener Hv953 (Ciba-Geigy), FR4, E-solder 3025 (IMI) (not complete)



Example of time evolution of current in HERA-B prototype chamber, showing Malter-effect

Factor I: Cathode Surface

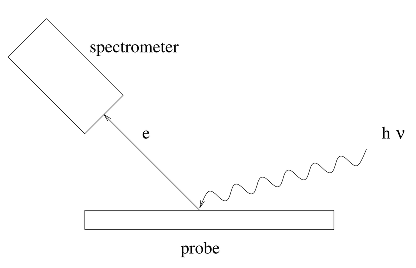
General condition for Malter discharges:
insulating layer on cathode, existing or building up under irradiation, after charging-up by positive ions, leading to sufficient electron emission for sustaining a stationary (corona) discharge for sufficiently high electron amplification.
Confirmation of this model for the case of cathode foil from POKALON-C, a polycarbonate based on Bisphenol-A, loaded with 6% of soot, with formula:



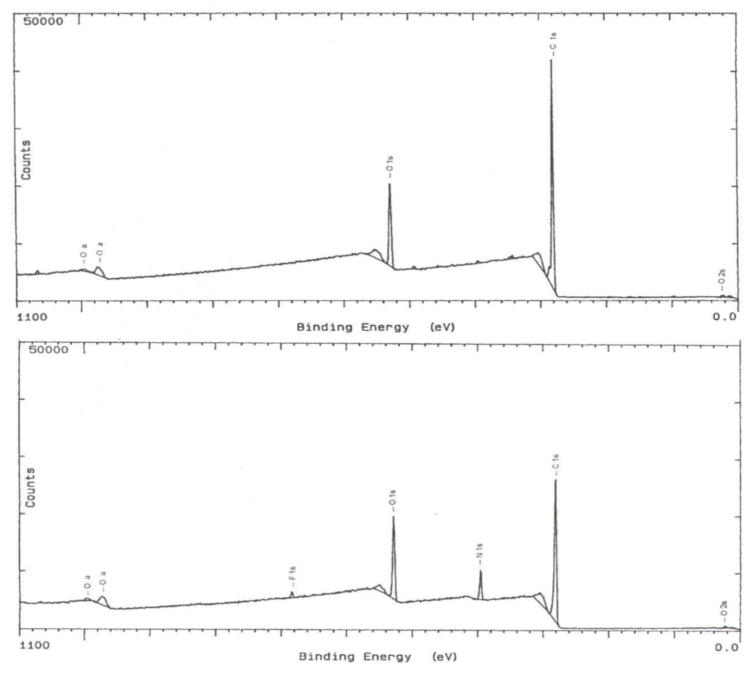
Investigation of surface properties:

1. Direct resistivty measurement (voltage drop for given current through foi):
- unsuccessfull, irregularities connected to surface roughness

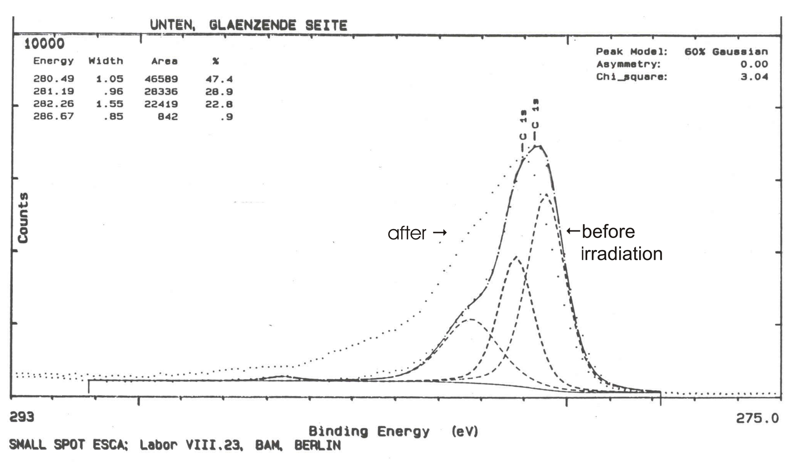
2. Chemical analysis of surface by (photo)electron spectroscopy (ESCA), principle:



Results and observations:
- charging-up of surface (positively)
- no soot seen (to depth 10 nm)
- on used foil: C-O-groups from Bisphenol-A (as seen on fresh foil) covered by plasma condensats, containing C-F and C-N groups.

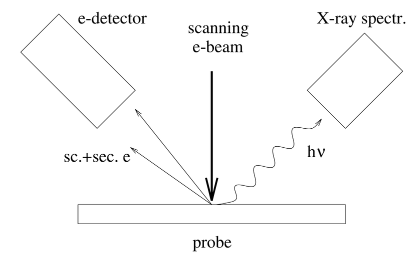


Esca spectra of POKALON-C cathode foil before (upper spectrum) and after (lower spectrum) irradiation (from region showing Malter-effect): N and F in organic bounds appear (besides expected CO groups).



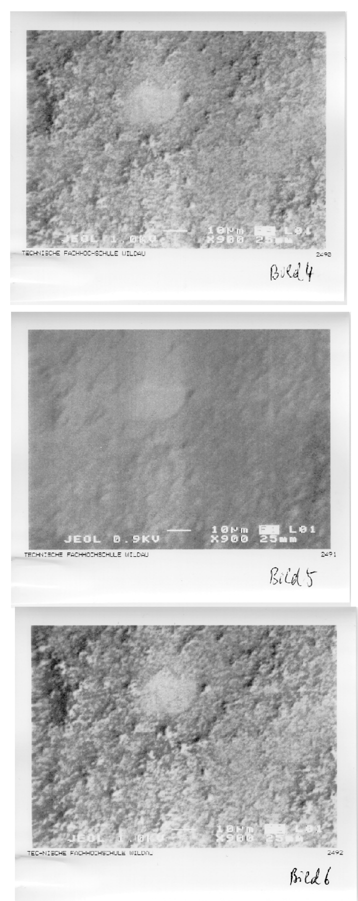
High resolution spectra from the same places show broadening of C-peak for irradiated foil, characteristic of plasma polymers.

3. Scanning secondary electron microscopy (SEM),
Principle:



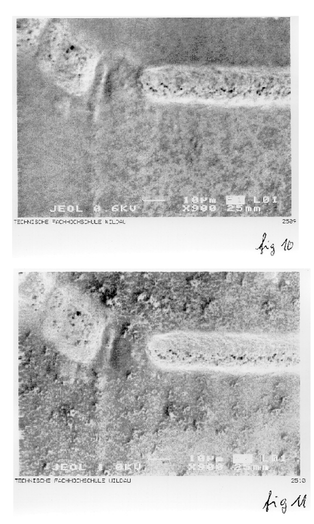
Observation:
- Reversible loss of contrast, if primary electron energy diminished below 900 eV (penetration depth below 100 nm).
- This effect is characteristic for 75 µm POKALON-C foil without treatment.
- Prevented by mechanical scraping, plasma-etching, conductive coating. Also not observed on 15 µm POKALON-C foil, ATLAS-straw foil.

Explanation: charging up of surface (in case of 75 µm foil too low conductivity in upper layer).



SEM-pictures of 75 µm POKALON-C foil for electron energies 1 keV, 0.9 keV, return to 1 keV: the contrast disappears (reappears) with threshold -like behaviour (lefthand side).

SEM-pictures of partially etched 75 µm POKALON-C foil (0.6 → 1.0 keV): the contrast (re)appears in the non-etched region only (upper and lefthand edge of pictures below).Lefthand edge of pictures below).



Factor II: Beam

The charging-up of an (insulating) cathode surface is related to the local ionisation current density, which in turn very strongly depends on beam conditions.

Malter-effect not clearly observed

Place	Several lab's	HMI Berlin	FZ Rossendorf	FZ Rossendorf	Zeuthen
Beam/energy	X-rays/ 35 keV	e^- / 2.5 MeV	/28 MeV	p/13 MeV	/4.5 MeV
Irr. dosis	Up to 5 C/cm	10 mC/cm	3 mC/cm	5 mC/cm	150 mC/cm
Remarks	Reexcitation possible	Not seen	Not reproducibly seen	Seen after increasing HV	Not seen

Malter-effect observed and confirmed

Place	HERA-B	PSI	PSI	FZ Karlsruhe
Beam/energy	Hadrons/undefined	Hadrons/350 MeV	p/70 MeV	/100 MeV
Irr. dosis	few mC/cm	few mC/cm	3 mC/cm	10 mC/cm

Conclusions:
- Only sufficiently energetic (> ~100 MeV) hadrons excite Malter discharges in new chambers
- heavily ionizing nuclear fragments have to play a prominent role.

X-rays produce more diffuse primary ionization; the total ionization current cannot be enhanced sufficiently due to space charge limitation
- local current density stays too low.

Reexcitation possible (in already sick chambers and chamber build from aged foil).

j_+^{max} may reach values much higher than mean current densities
$j_+^{max} \approx$ 3.4 mA/cm^2 >> $\langle j_+ \rangle \approx 1$ cm
(see box "parameters and relations").
The lifetime of ion layers extends over many orders of magnitude: practically no charging - up, if surface resistivity comparable to bulk resistivity of POKALON - C, otherwise nearly unlimited for insulating surface layers.

Parameters and Relations

Change of surface charge density n :

$$\frac{dn}{dt} = j_+ - j_-,$$

$$j_+ = \frac{Q}{\Delta t\, \Delta z\, 2\pi r_a},\quad j_- = E_{SC}/\rho = n/(\varepsilon\rho)$$

Q – charge / particle hit
Δt – duration, Δz – extension along chamber for ion cloud hitting cathode at radius r_a,
E_{SC} – electric field of surface charge,
ρ – resistivity,
ε – permittivity of surface layer

Numerically :

$Q \simeq 10^6 \div 10^8\, e$ (for MIPs / HIPs),
$\Delta t \simeq 1\,\mu s$, $\Delta z \simeq 30\,\mu m$,
(from diffusion of ions and electrons),
$r_a = 2.5$ mm,
$\Longrightarrow j_+ = 34\,\mu A/cm^2 \div 3.4\, mA/cm^2$
$\Longrightarrow \tau = \varepsilon\rho \simeq 3\cdot 10^{-13}\, s \div 3\cdot 10^3\, s$
(for POKALON – C / pure polycarbonate)

Factor III: Gas

The influence of gas mixture including impurities from leaks and outgassing was not studied systematically. The following observations are to be considered as indications.

CF_4/CH_4 (80/20): Strong Malter effect, not affected by addition of H_2O (up to 0.5%), but partially cured by ethanol (the latter excluded, however, for its negative influence on glue stability).

$Ar/CF_4/CH_4$ (74/20/6) (Voltage lowered to 1600 V): Malter effect observed, partly superseded by strong anode aging.

$Ar/CF_4/CO_2$ (65/30/5) (Voltage lowered to 1700 V): typically effect difficult to reproduce . Observed in experimental area only, no special aging tests.

The change to a gas not containing hydrocarbons nor impurities from outgassing of Araldit seems to remove the memory effect, probably because plasma polymerisation is inhibited.

Gas flow effects: In case of (plasma)chemical processes to be expected, if diffusive exchange of neutral species involved. Indeed it was observed that Malter-currents grow, if gas flow is enhanced to very high values.

The ultimate remedy: conductive coating

(Higher insurance against occasional Malter effect by gas $Ar/CF_4/CO_2$)

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