Comparison of reactive and ceramic AZO and ITO from dual rotatable magnetrons

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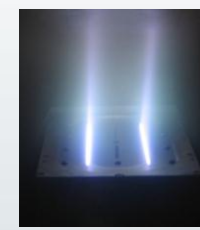
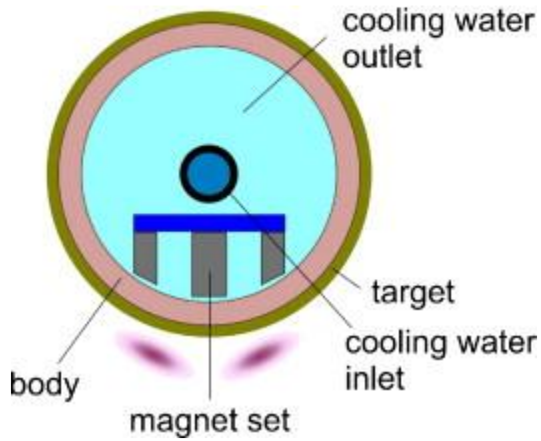
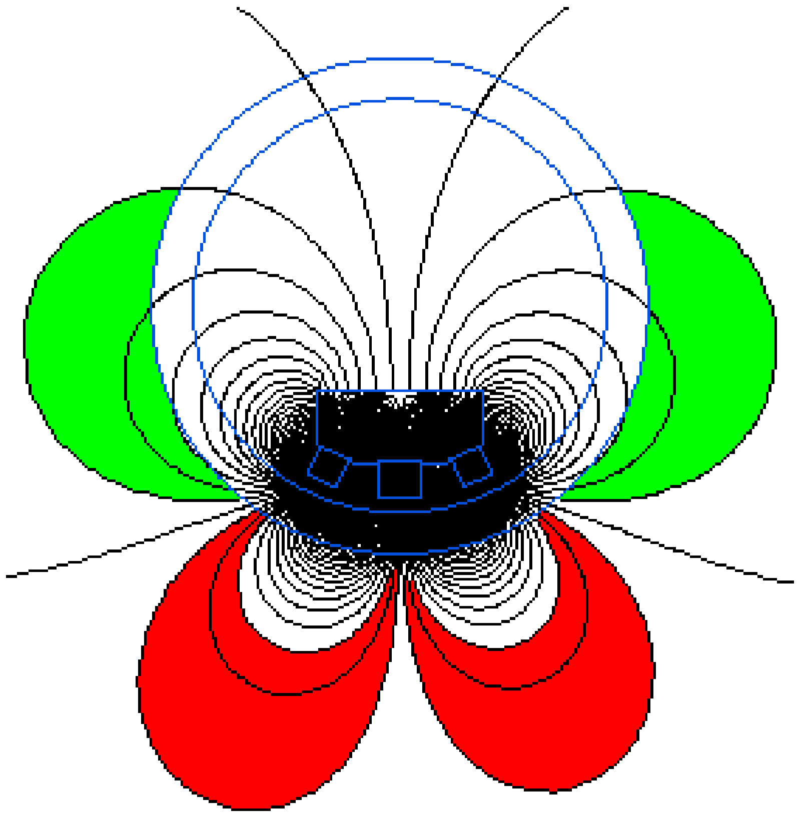
Structure of presentation

- Overview of basic magnetic designs for rotatable magnetrons for DC and AC sputtering
- Anode importance in rotatable magnetrons and effect on substrate heating and plasma interaction
- Magnetic options for rotatable magnetrons with positive guiding of plasma electrons
- Case study: electrical and optical properties of reactive and non-reactive AZO layers formed with different rotatable magnetic geometries
- Case study: electrical and optical properties of reactive ITO layers formed with different rotatable magnetic geometries
- Conclusions



Whilst for a planar magnetron discharge and anode can be used to confine the plasma, typically for rotatable magnetron no anode is close-by





Accurate positioning of the magnetic field to ensure erosion to the end of the target

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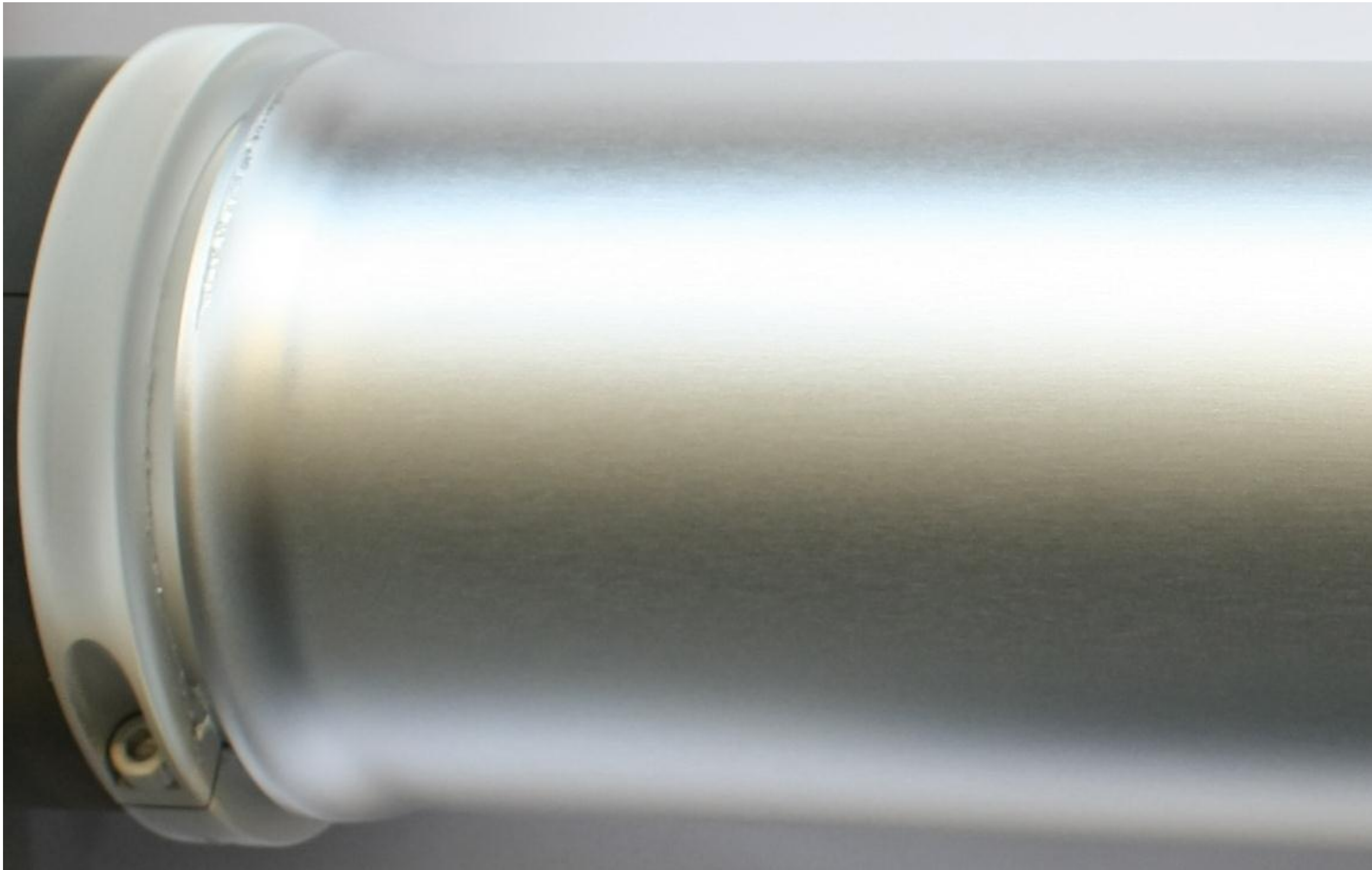
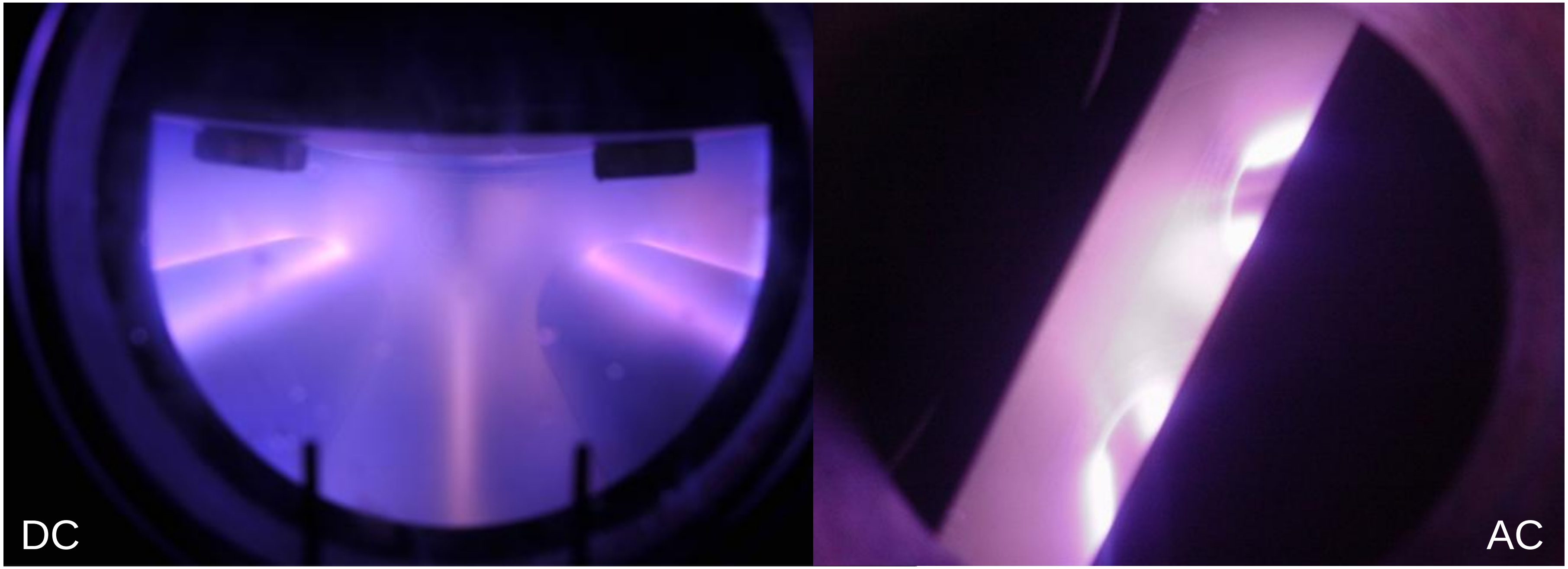
No reaction product on the surface – cleans itself



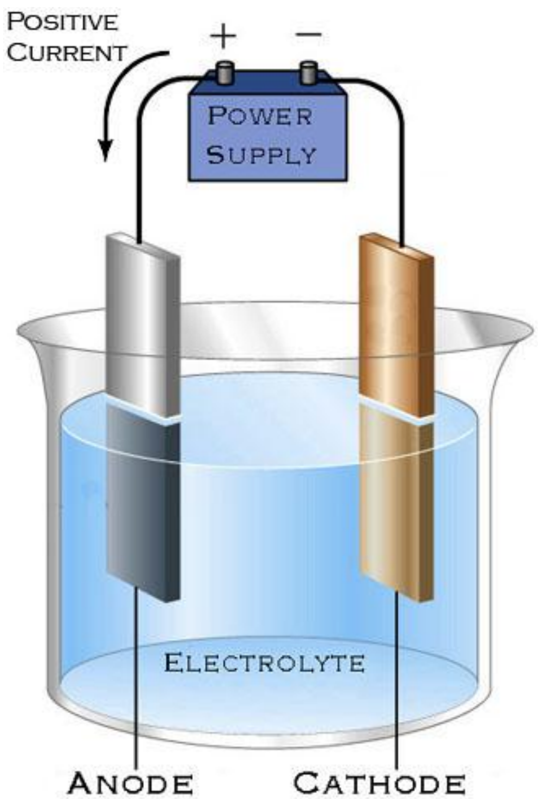
Absence of anode can be seen in a plasma spread away from the target area

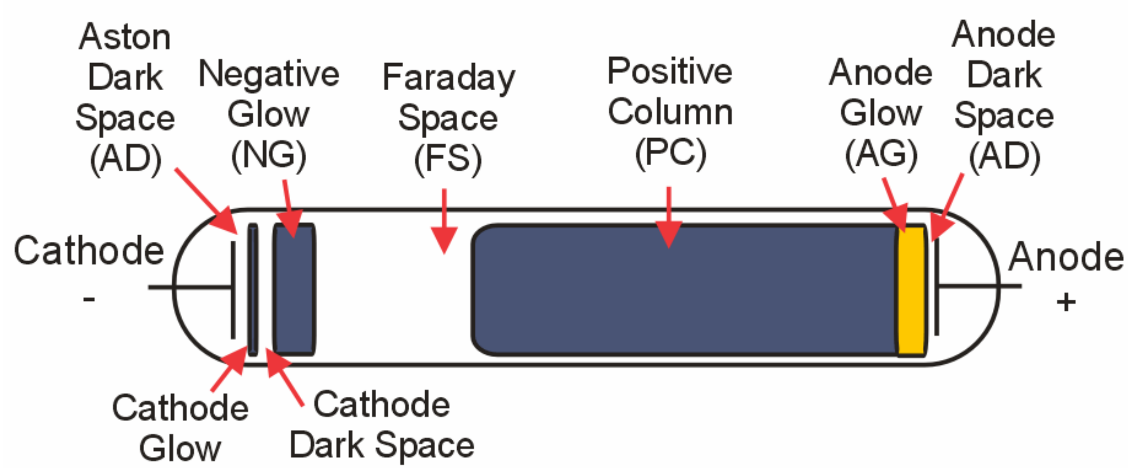


• A plasma is effectively an electric circuit with the target a negatively biased cathode and the chamber or separate mean providing the anode for the circuit return.

• Anodes are commonly earthed, although a positive charge is also possible.

• Whilst the plasma confinement in the near target area is governed by the magnetic field, the plasma spread away from the target is primarily an anode interaction effect.





For single magnetrons or for DC discharges anodes needs to be different to the AC pair case, hence a magnetically linked auxiliary anode is used

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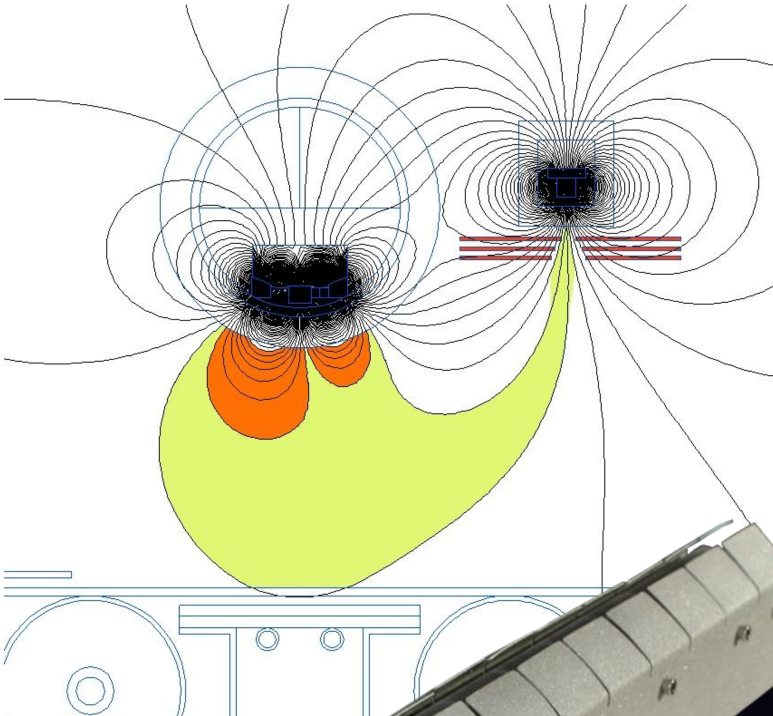
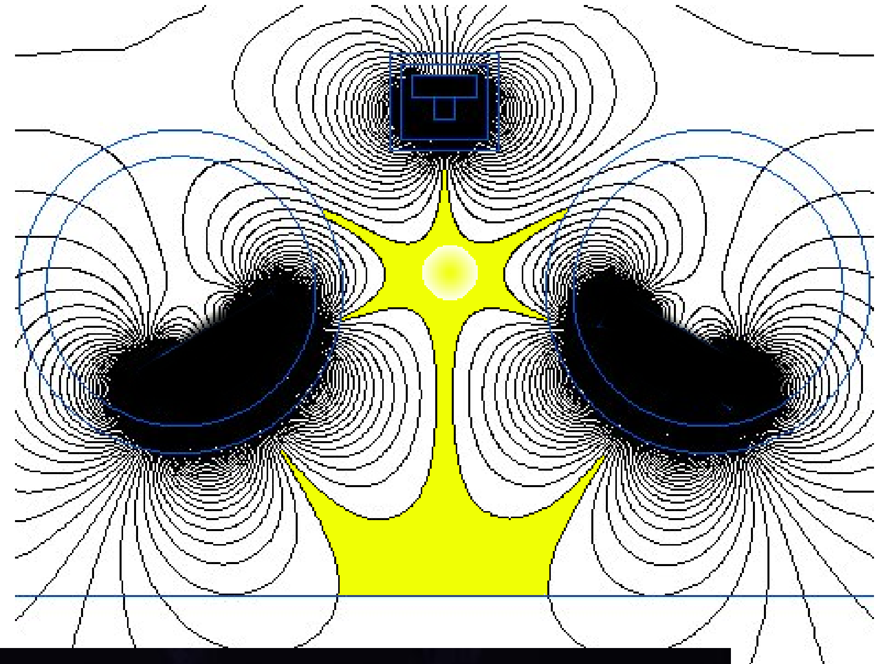
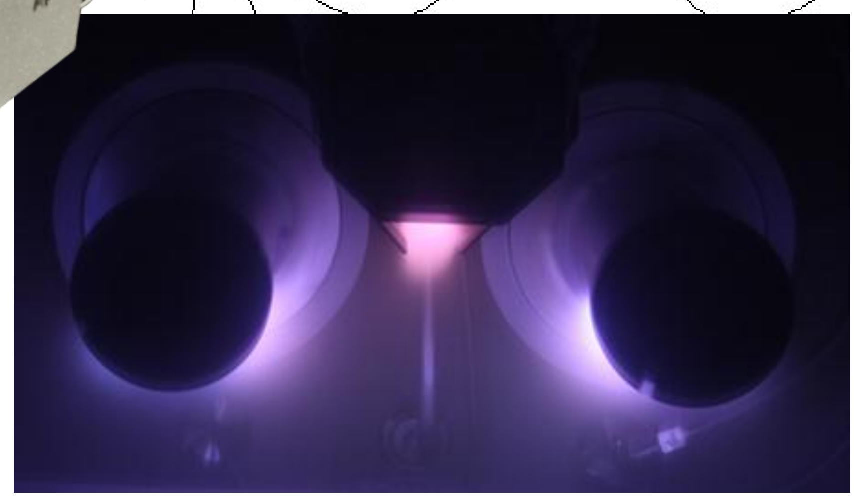
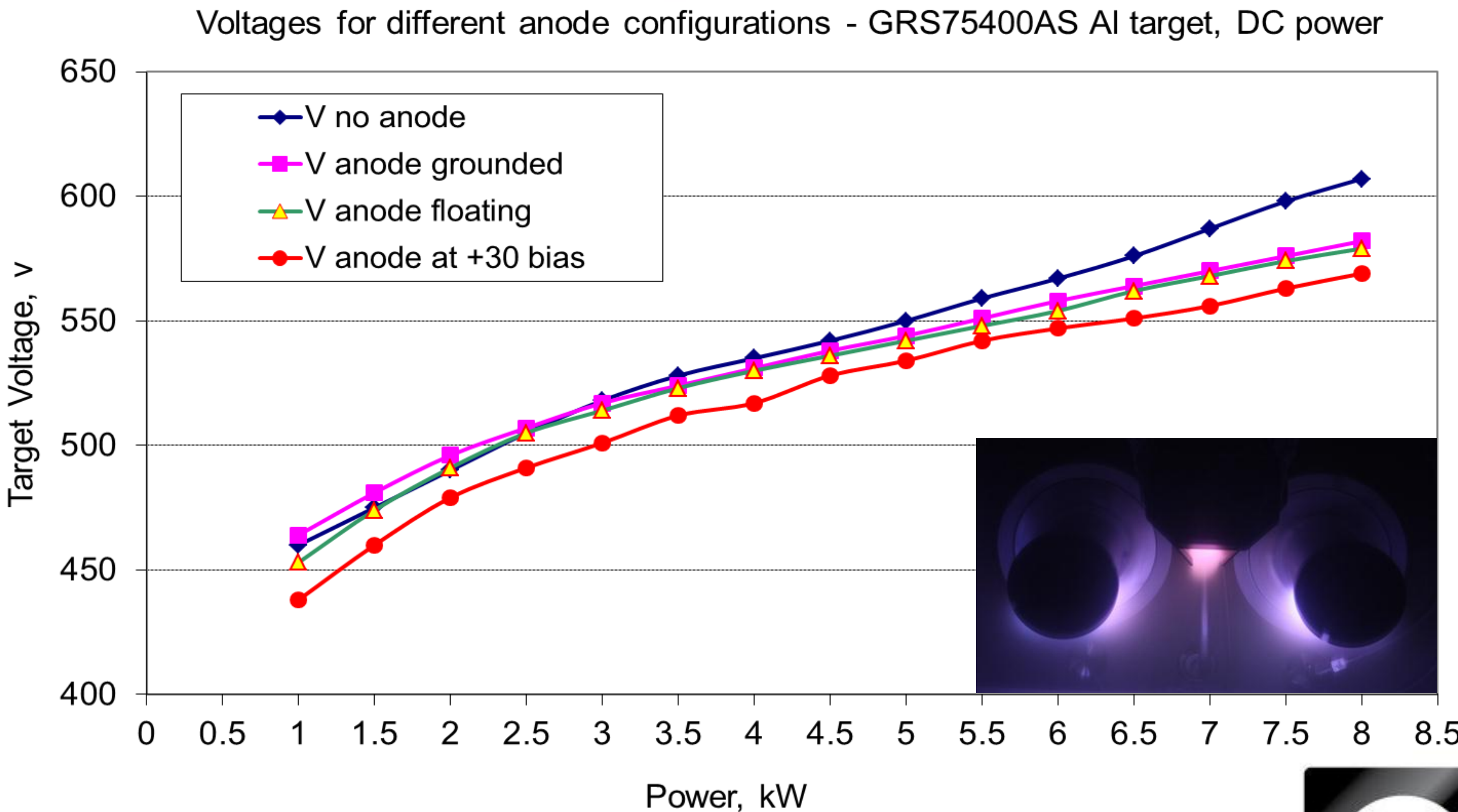




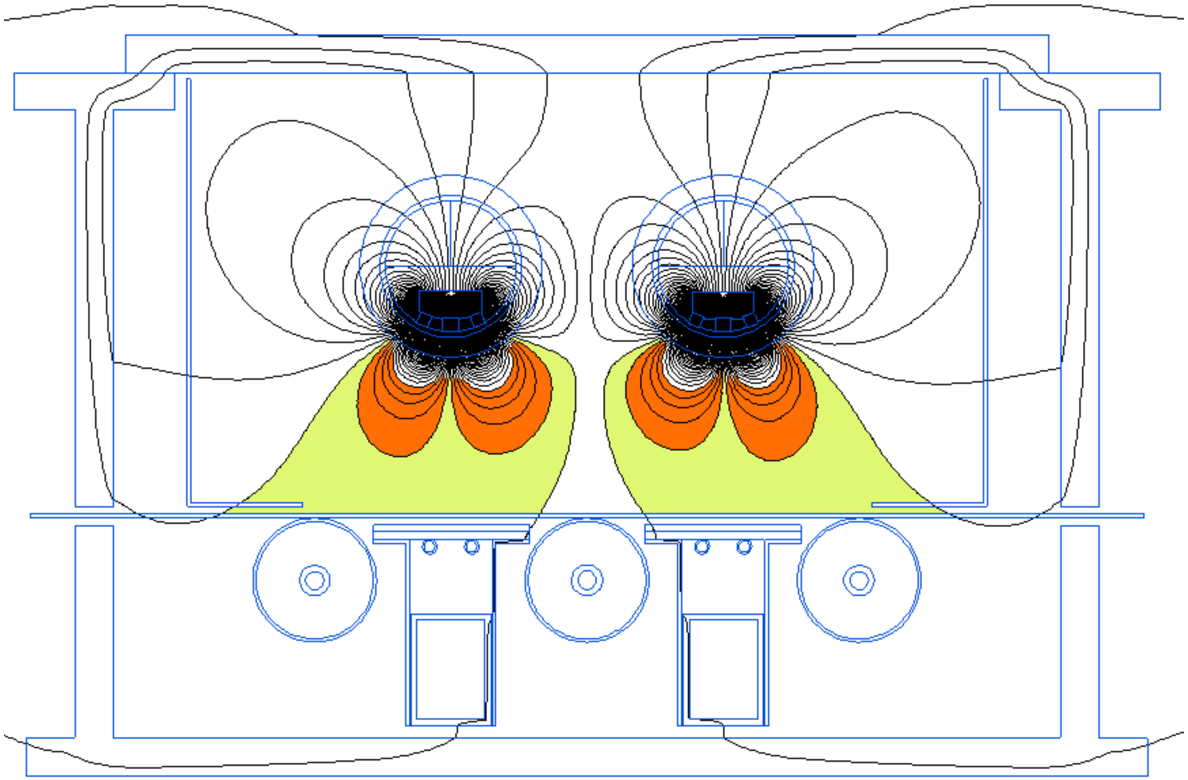


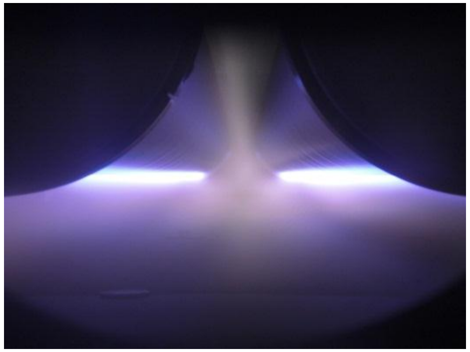
Effect of active magnetically guided anode on the sputter target voltage for a GRS75 – 75mm

OD dual DC powered arrangement & Al target material

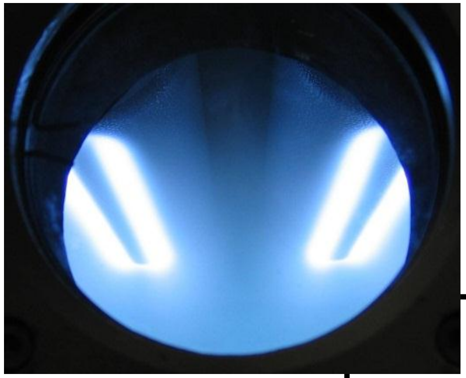


Magnetic design for a double magnetron used in industry currently

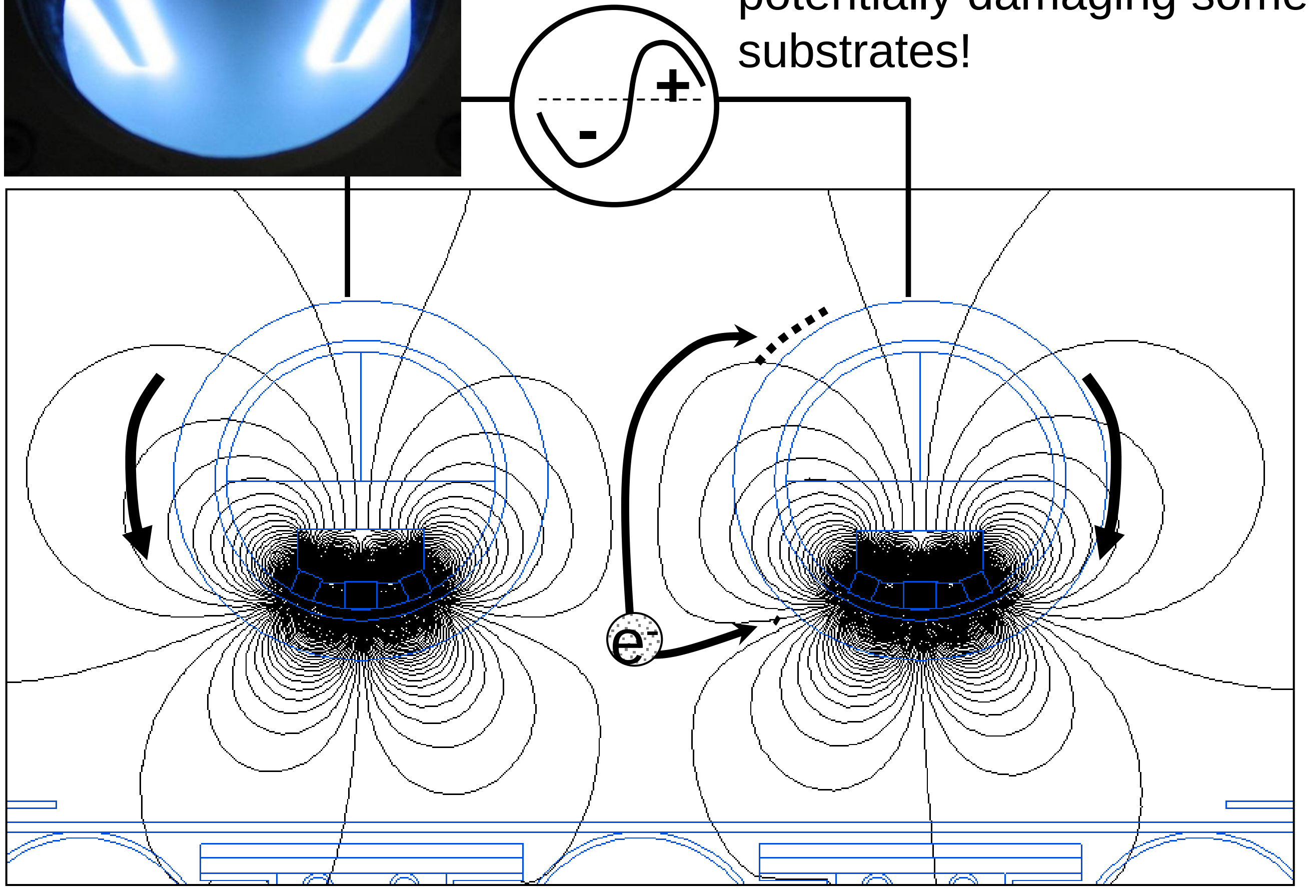


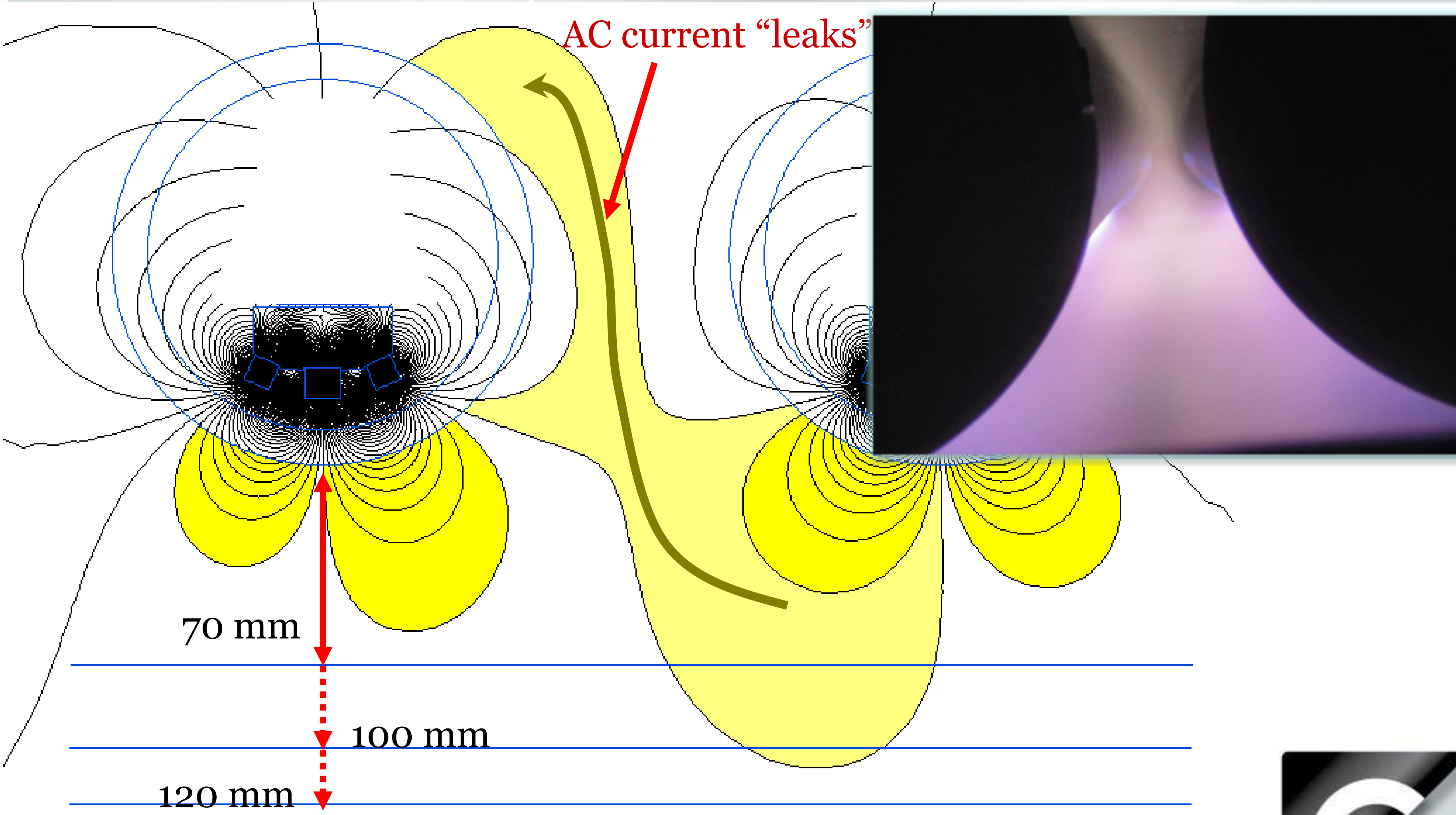


The above is the conventional magnetic arrangement for rotatables used by all manufacturers.

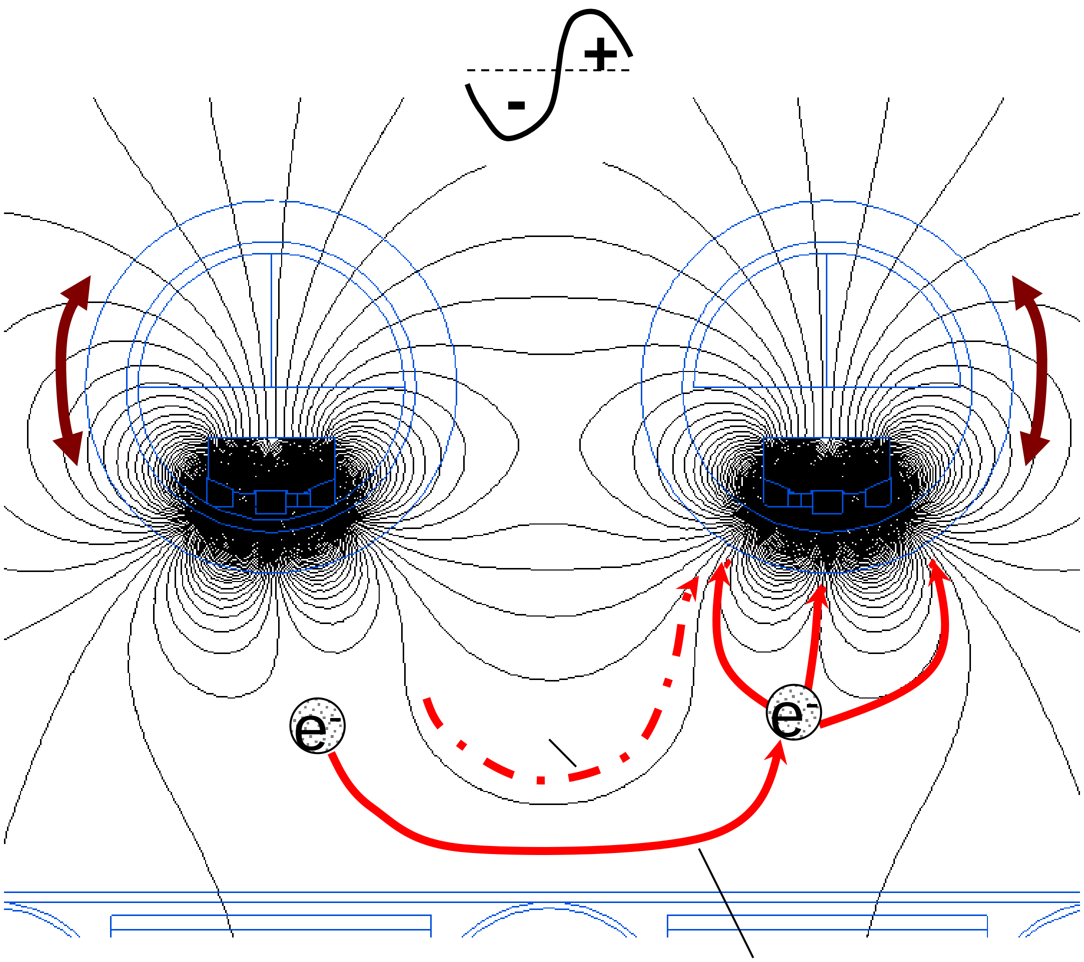


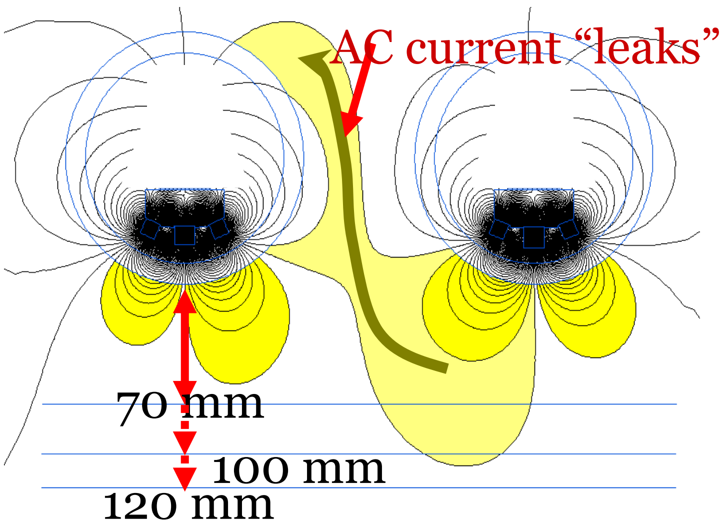
- AC provides excellent arc suppression – perfect for reactive oxides and TCO’s
- But increases the plasma at the substrate – potentially damaging some layer structures and substrates!




AC current "leaks"
70 mm
100 mm
120 mm

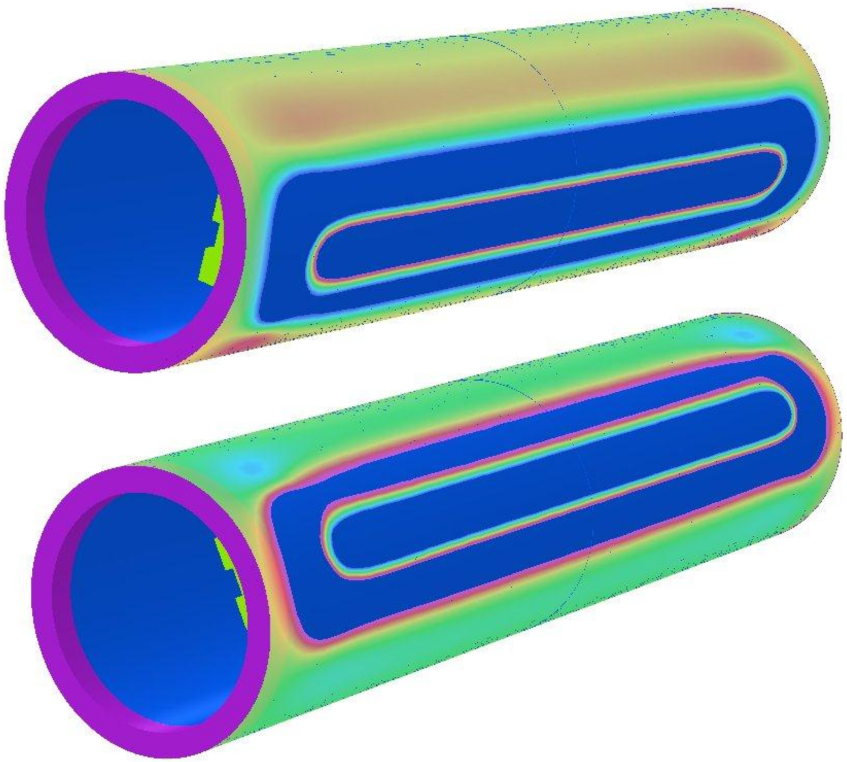
Lower impedance 'linked' magnetics as a solution for better plasma control away from the target area

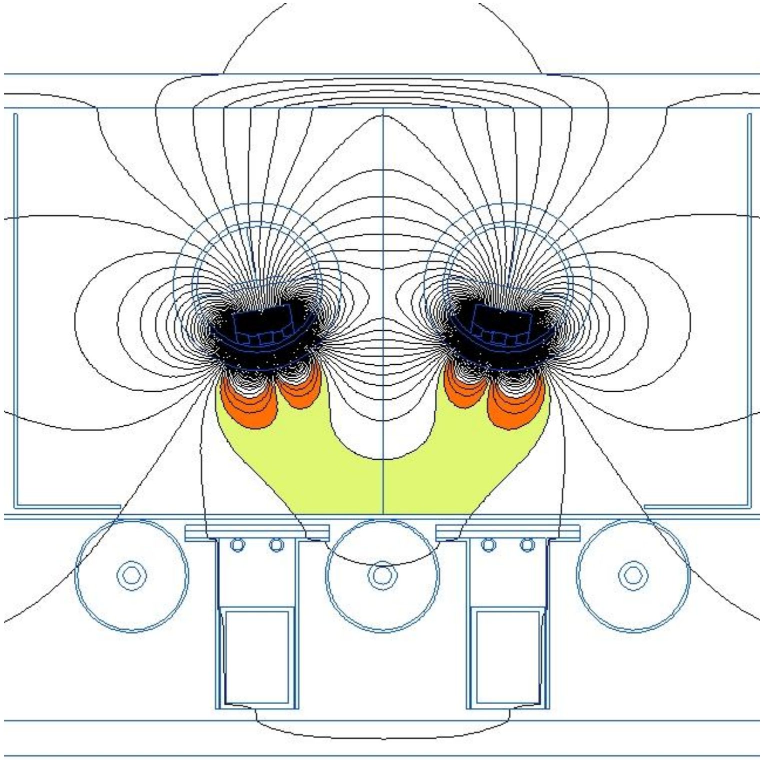


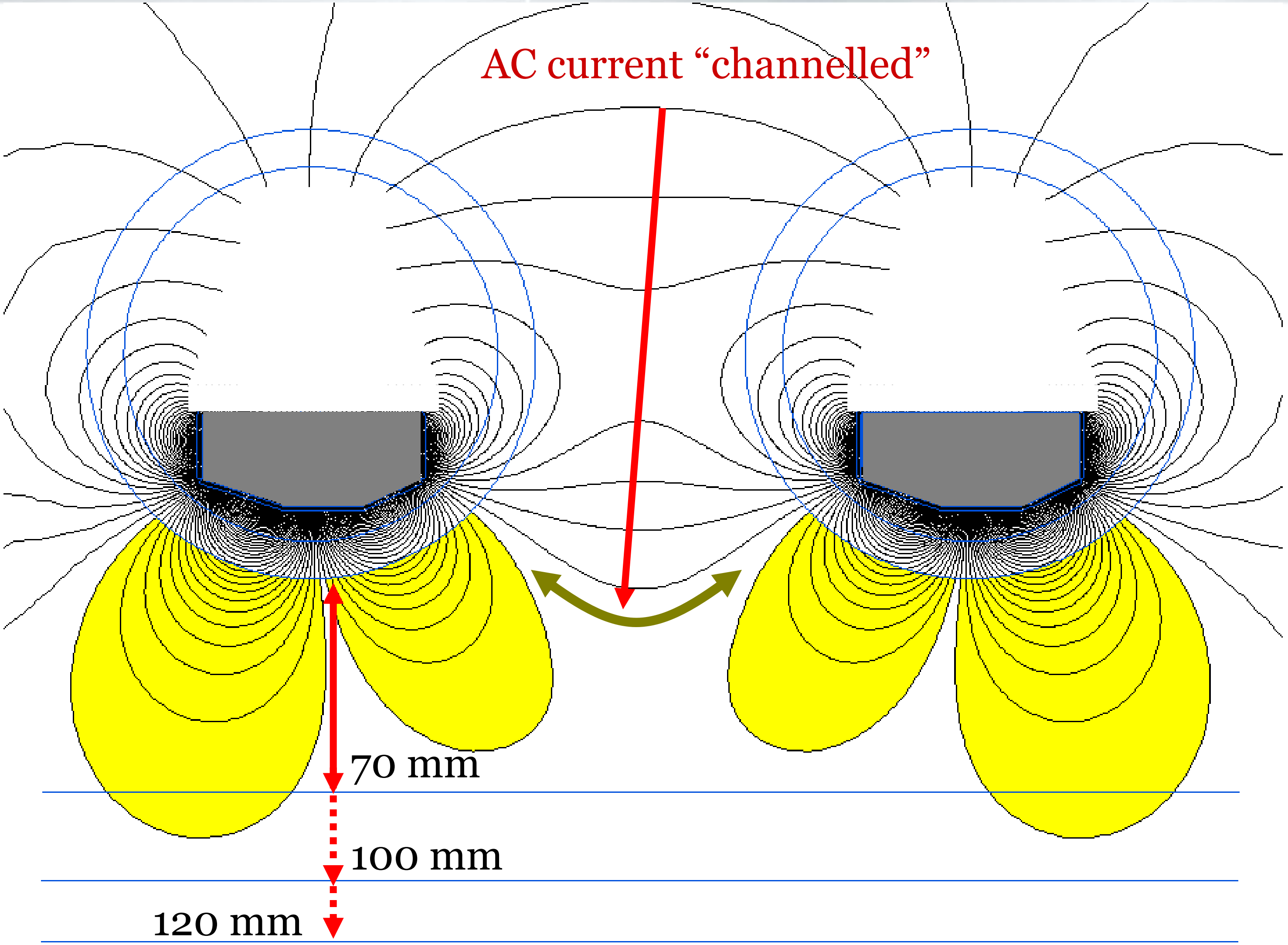


Plasma to substrate interaction by assymetric magnetics and tilting

Gencoa patent

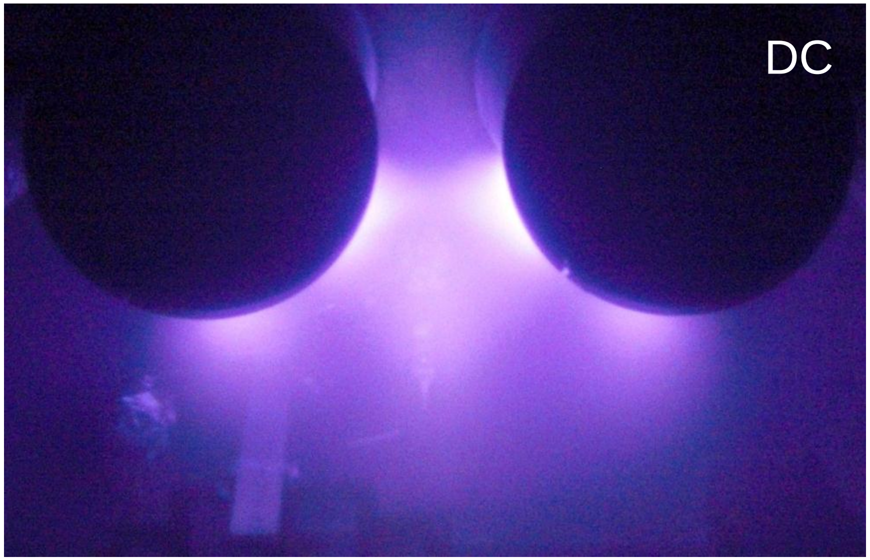


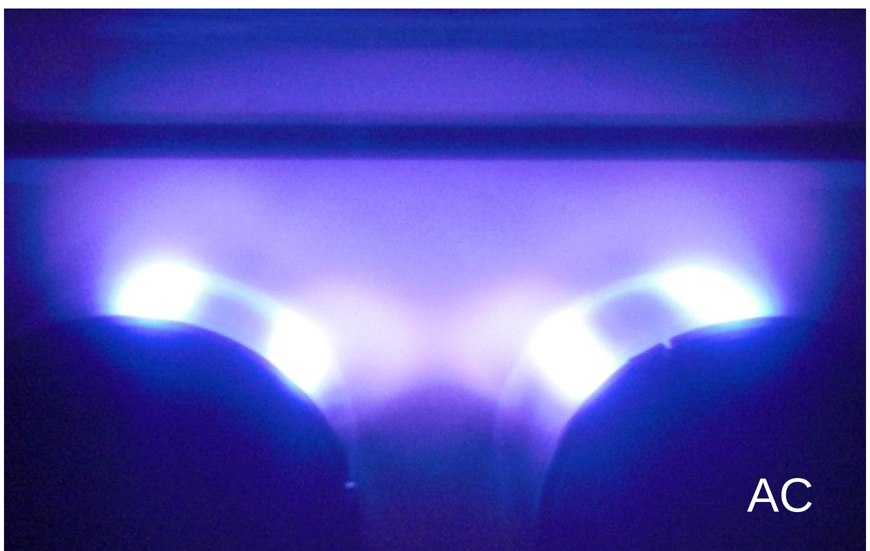


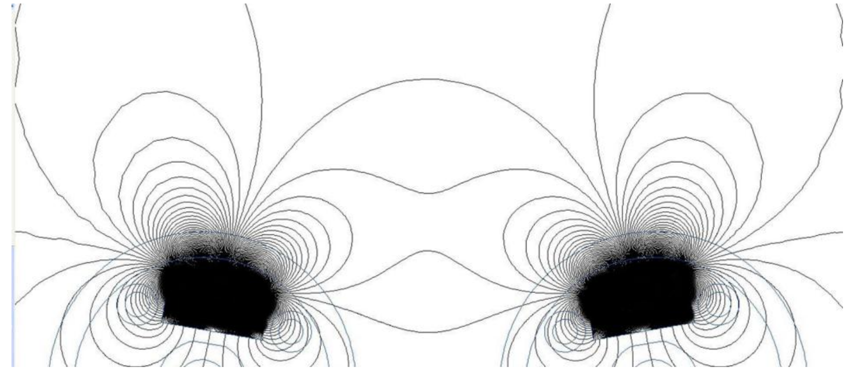

AC current "channelled"
70 mm
100 mm
120 mm

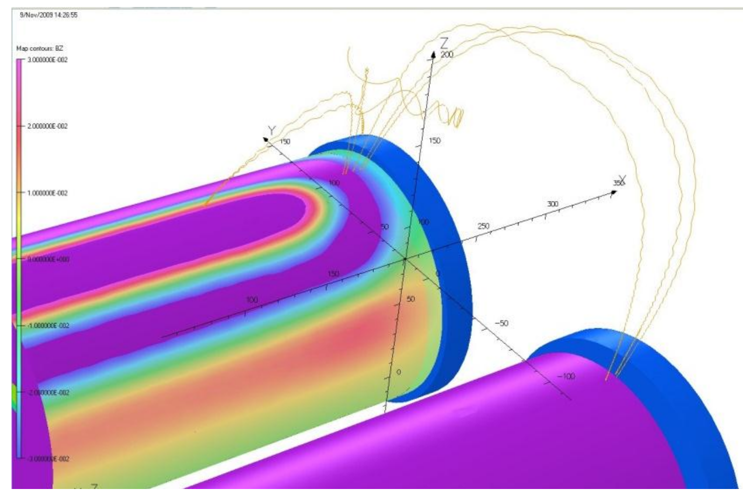
Plasma control by Double Low Impedance Magnetics - DLIM

Adjustment of angle relative to substrate position









Comparison of substrate temperature in-front of a double AC rotatable magnetron

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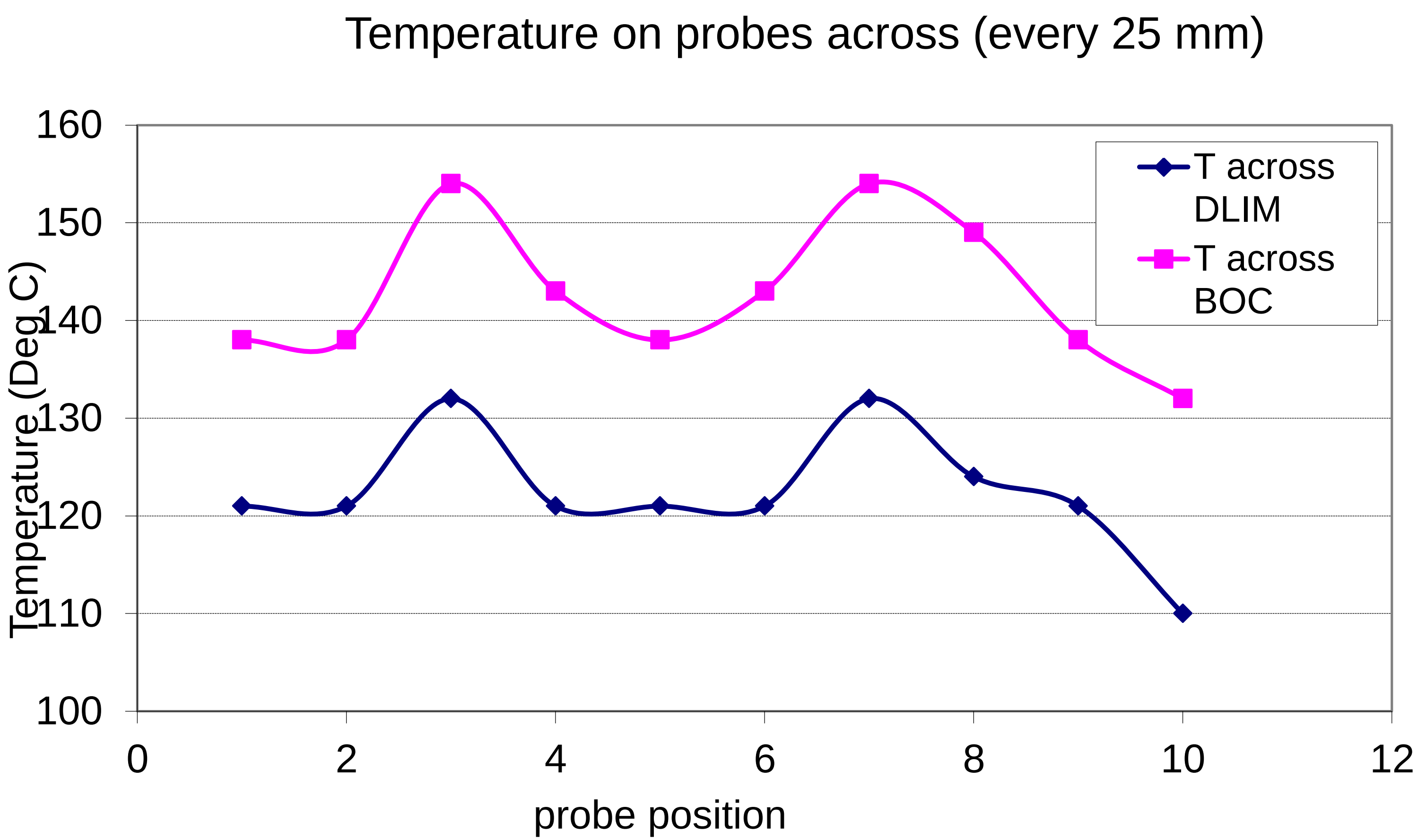
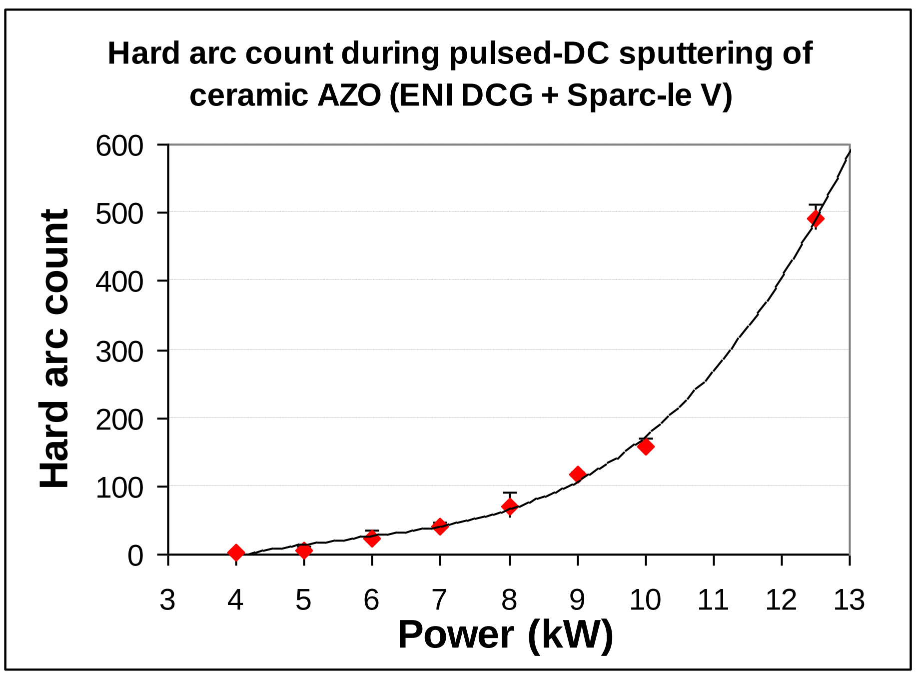
DLIM has a 20℃ lower temperature for same conditions



CASE STUDY use of DLIM and standard magnetics to compare AZO layers from ceramic targets with AZO layers deposited reactively

- Moderately expensive ceramic targets and bonding
- Micro-arcing – leads to variable & non-optimum product quality – adds power modes and material costs
- Long target burn in before stable film properties can be > 24hrs
- Possible plasma damage of growing film - increasing resistivity,
- Limitation of composition and crystal structure – good and bad



* SCI – Sputtering Components Inc

Ceramic AZO layer properties – variation of properties with process parameters

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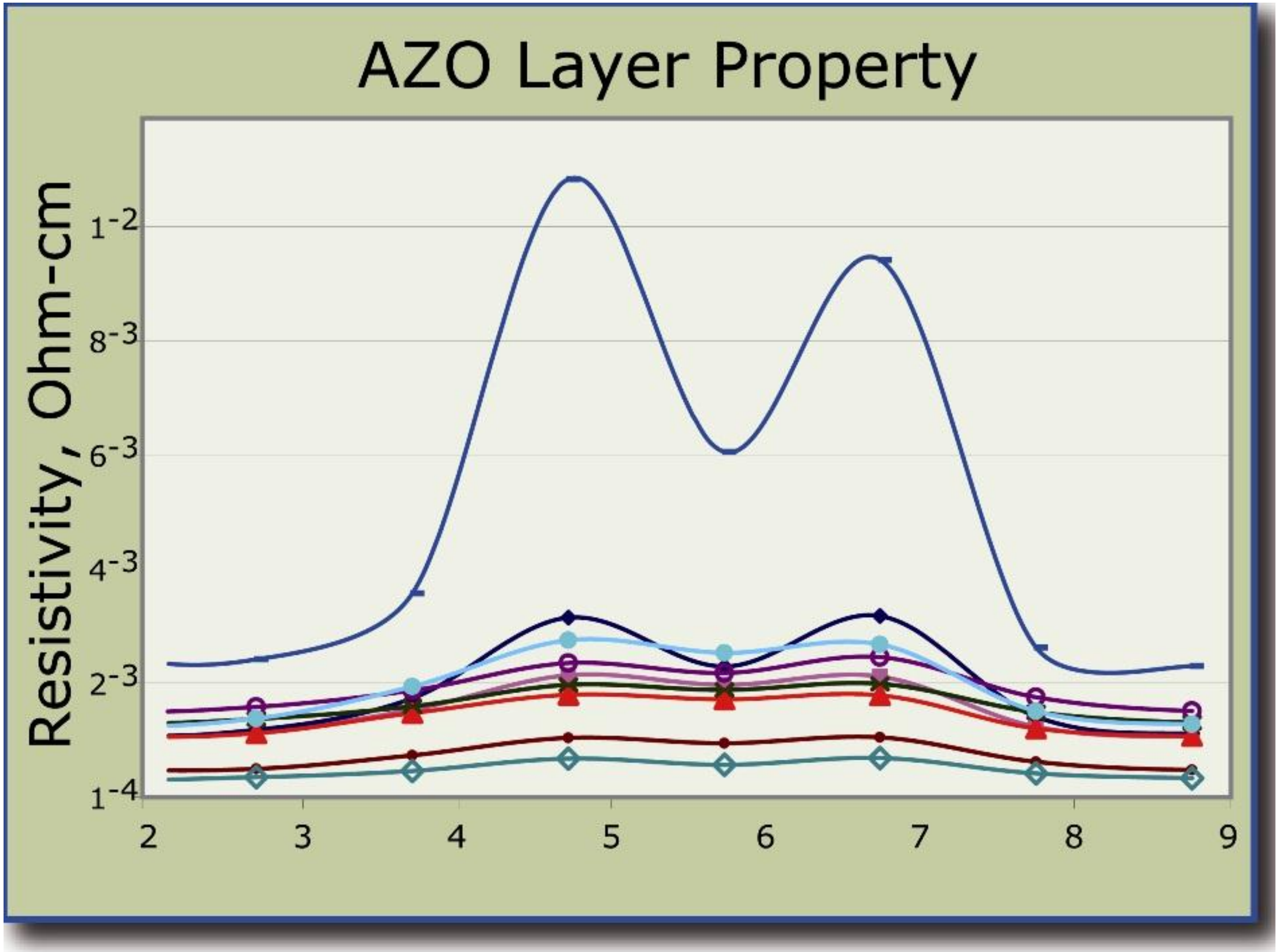
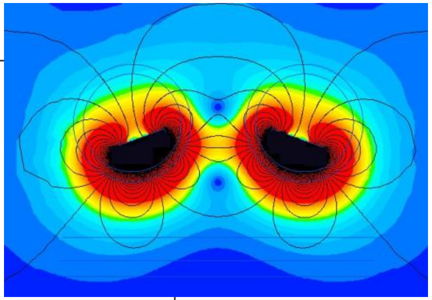
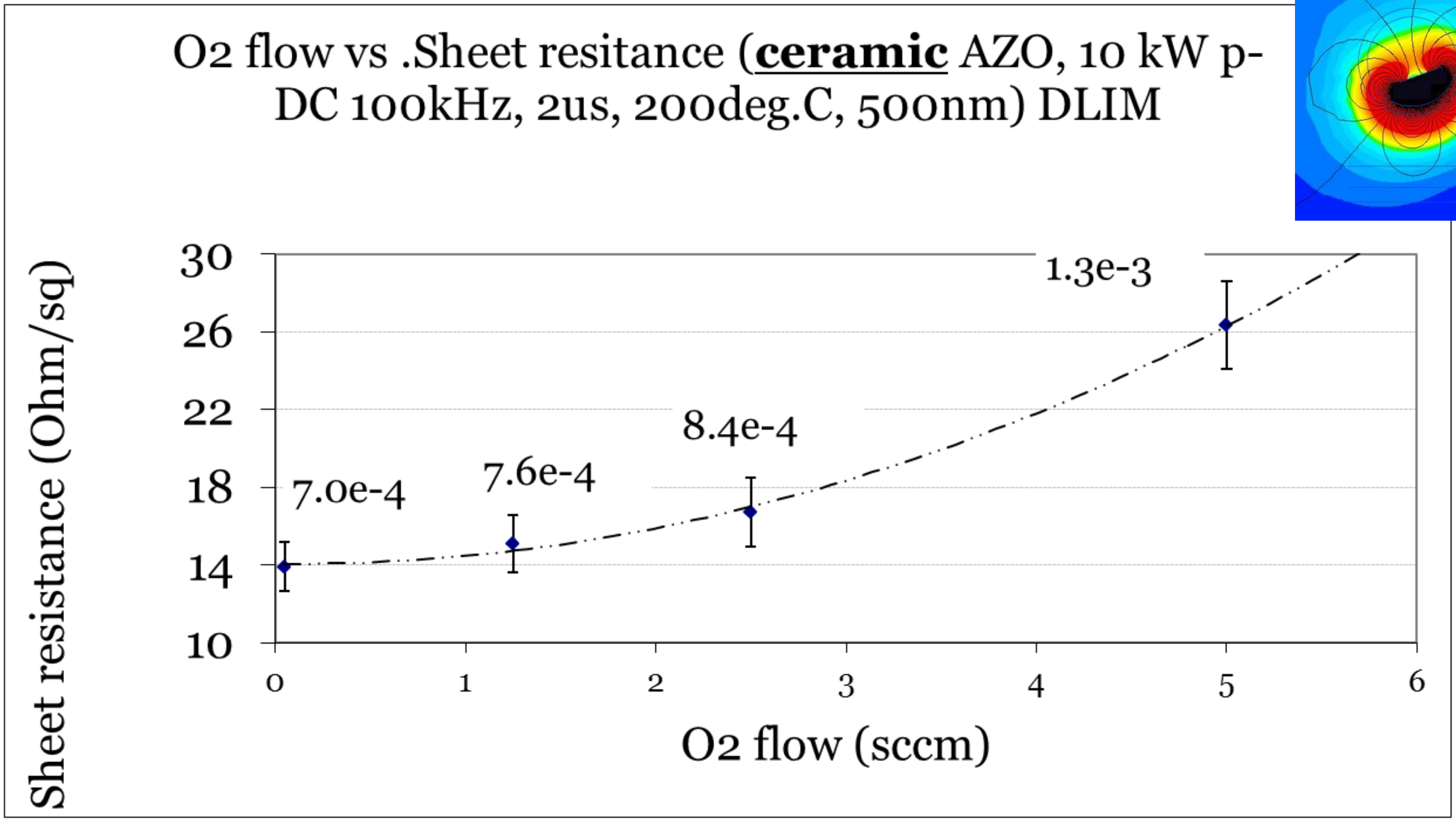
Problematic but presents an opportunity to improve



Variation of AZO properties for DLIM dual rotatable cathode with pulsed DC power

Variation of sheet resistance and resistivity with O2





Variation of AZO properties for DLIM dual rotatable cathode with pulsed DC power

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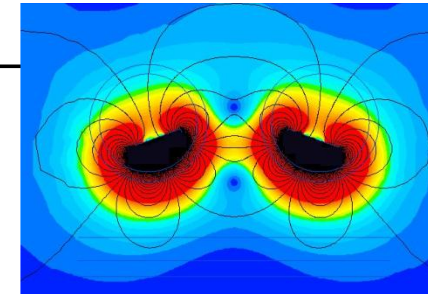
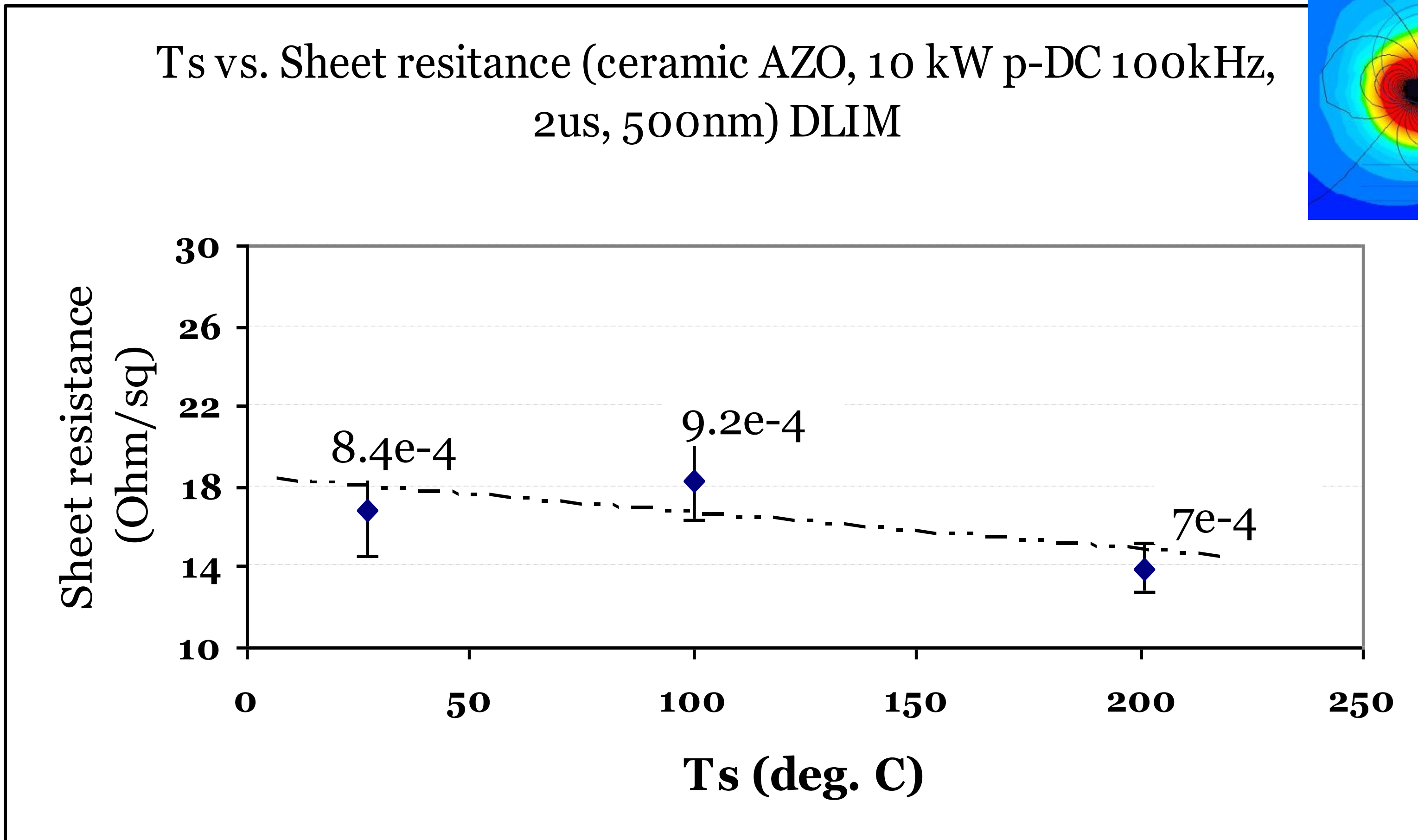
Variation of sheet resistance and resistivity with T

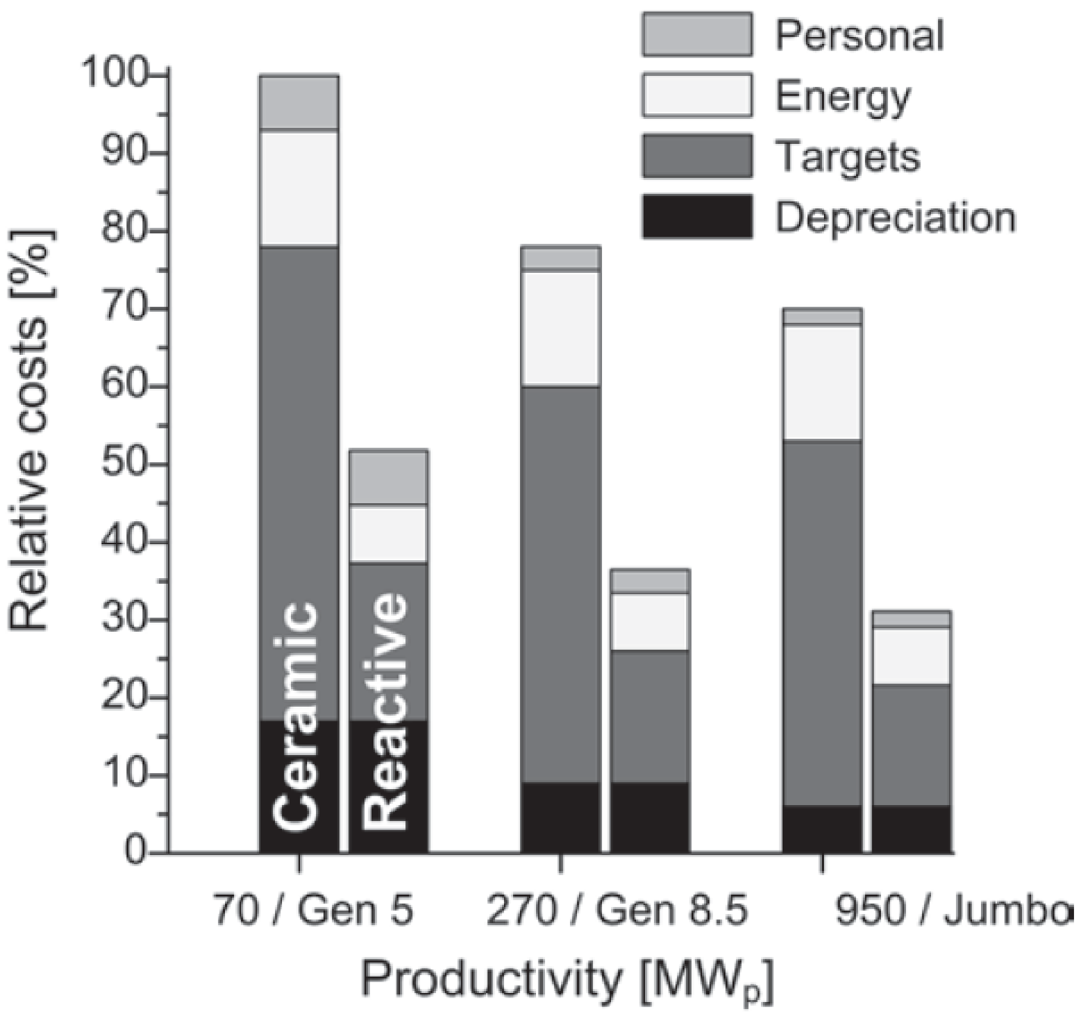




Controlled reactive sputtering is x 3 the rate in production than ceramic AZO

Price will be < 50% current ceramic based costs

*** Szyszka et al**



Different sensor control modes possible for reactive AZO via feedback controller

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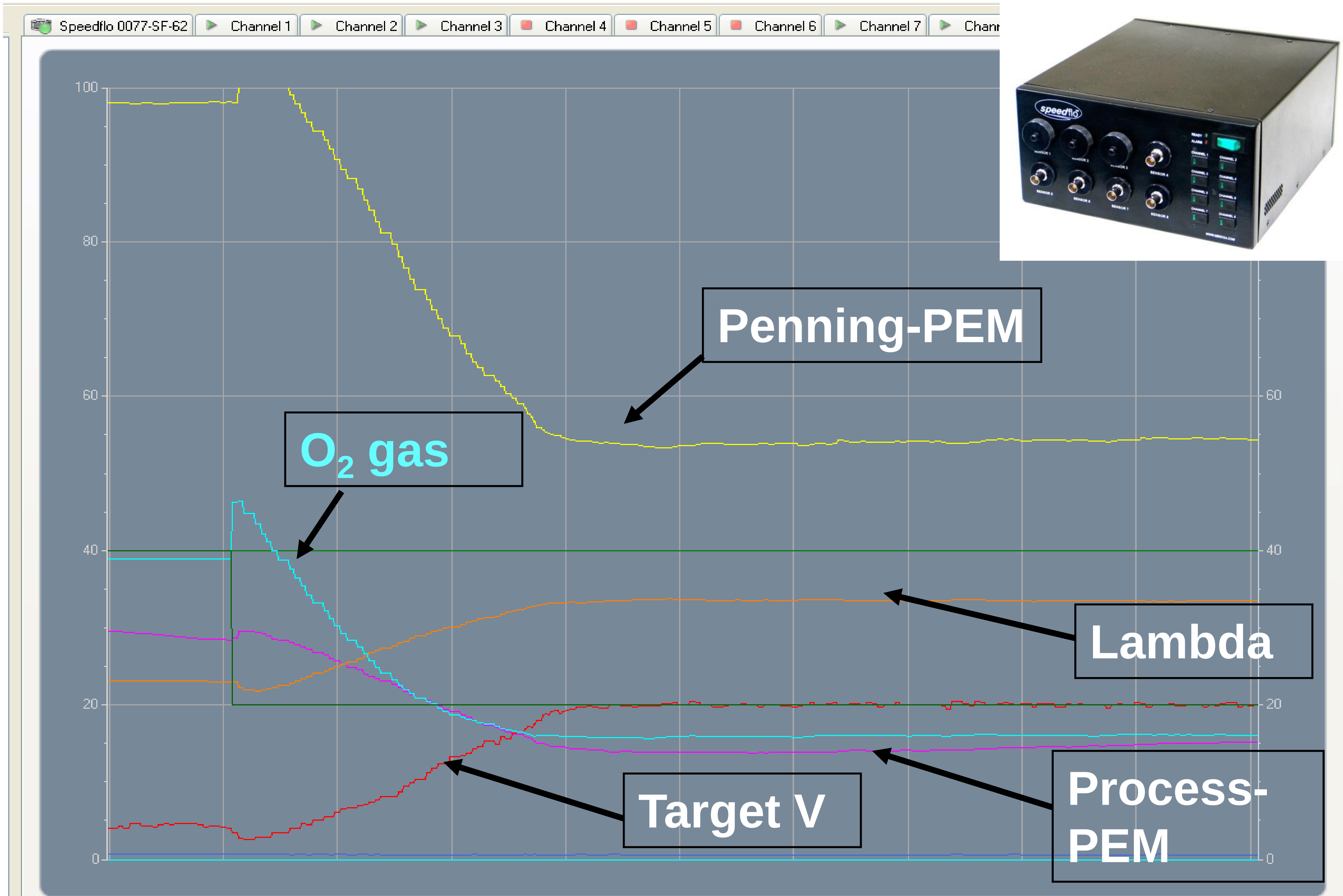
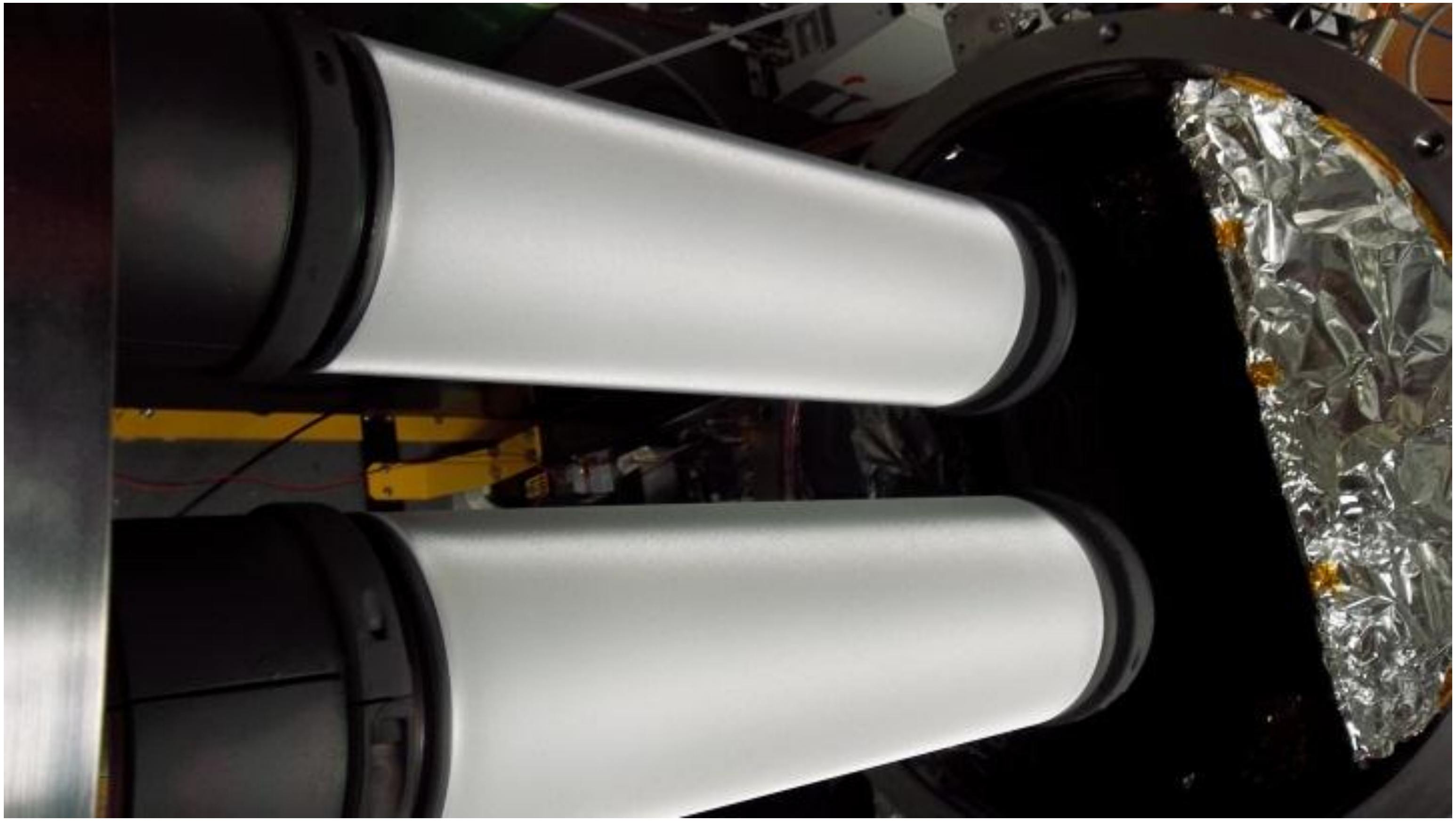


Basic process parameters for all depositions

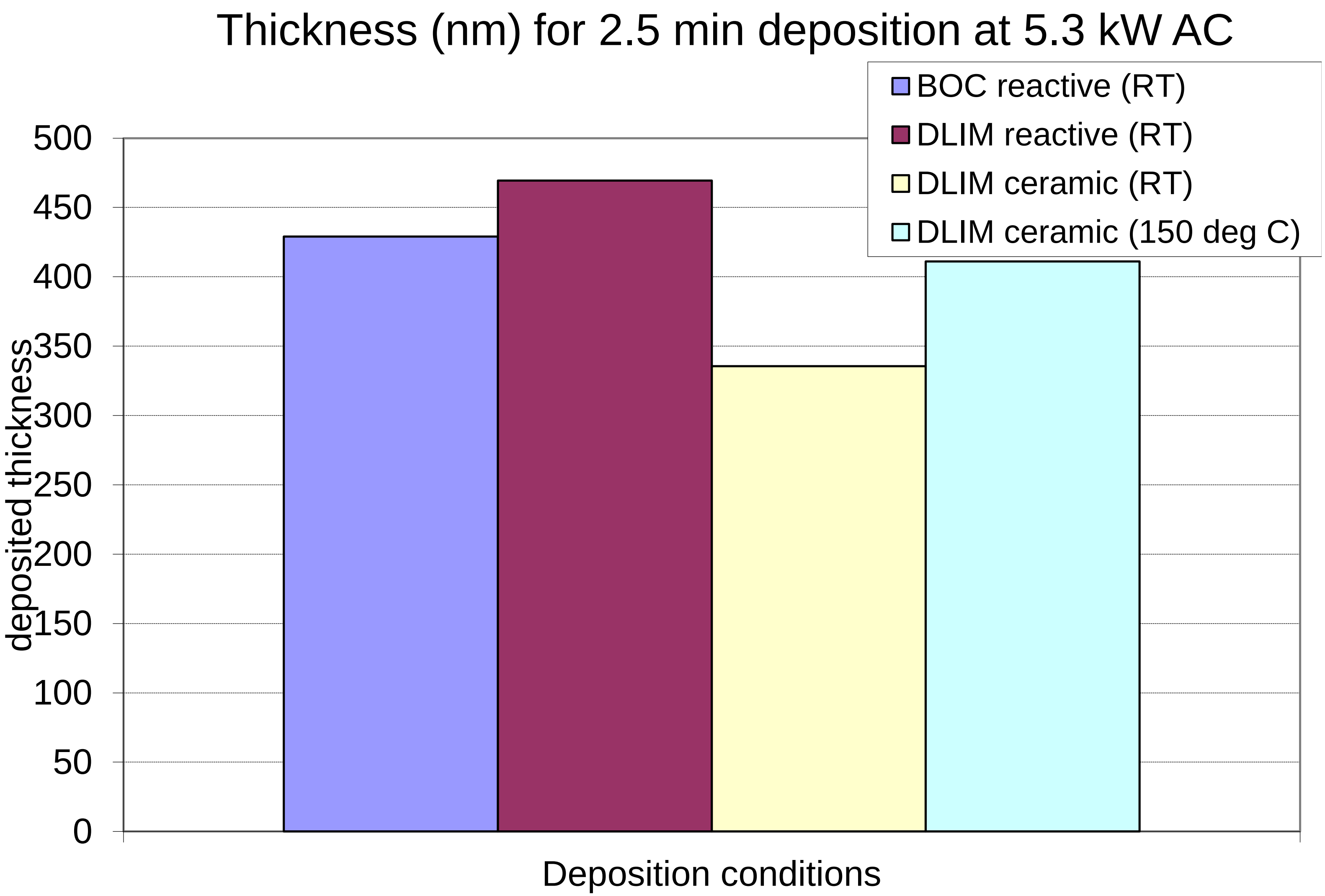


ZnAl: 152 mm diam x 475 mm L

AC-MF: 5.3 kW (Huettinger)

Ar press.: 3E-03 mbar

target rotation speed: 5 rpm
Substrate static
T/S: 95 mm
Temp: Room Temp.
Dep. Time: 10 mins


Thickness (nm) for 2.5 min deposition at 5.3 kW AC
BOC reactive (RT)
DLIM reactive (RT)
DLIM ceramic (RT)
DLIM ceramic (150 deg C)
deposited thickness
500
450
400
350
300
250
200
150
100
50
0
Deposition conditions

Comparison of electrical properties for ceramic AZO, standard (BOC) & DLIM without substrate heating and AC power

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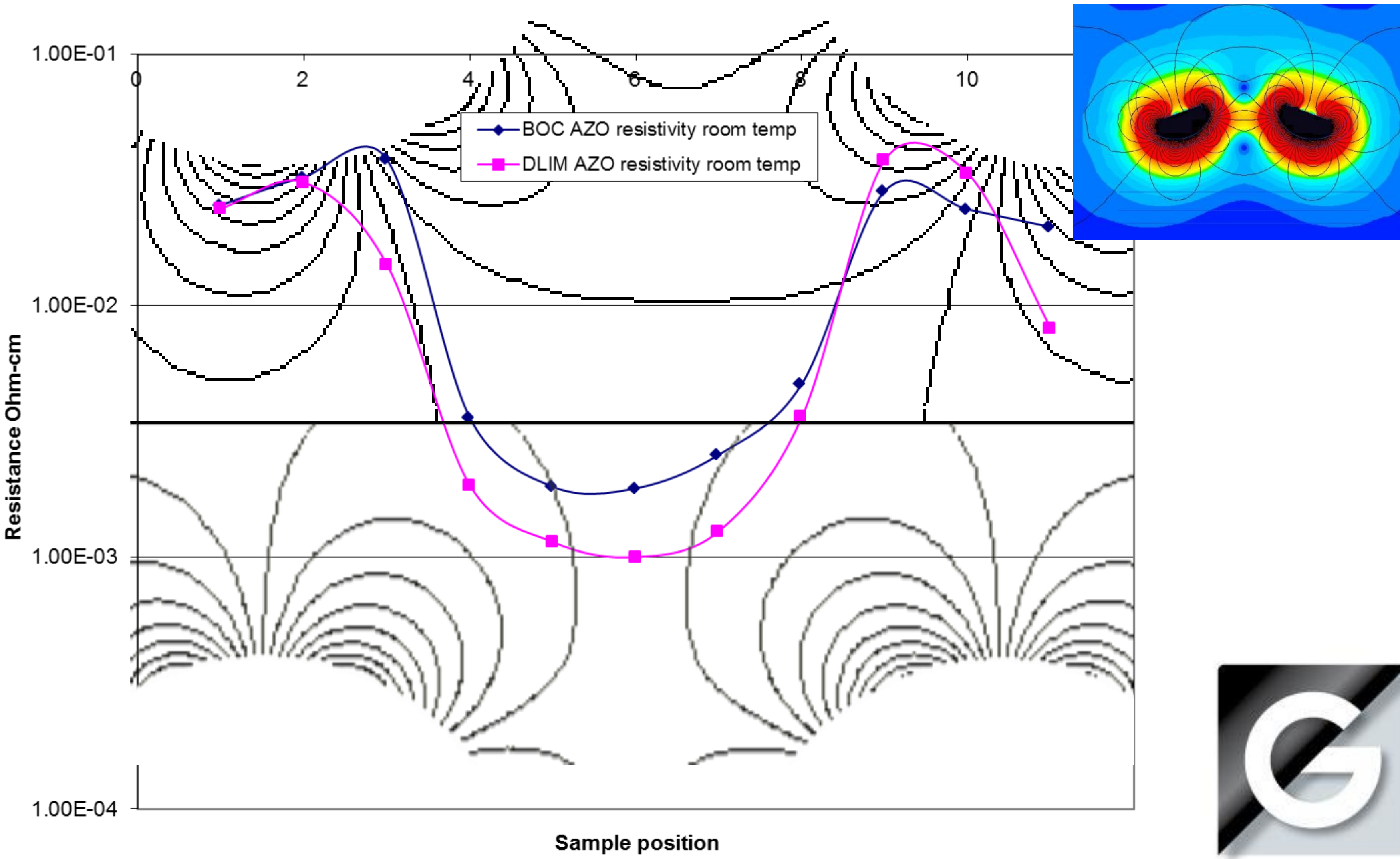
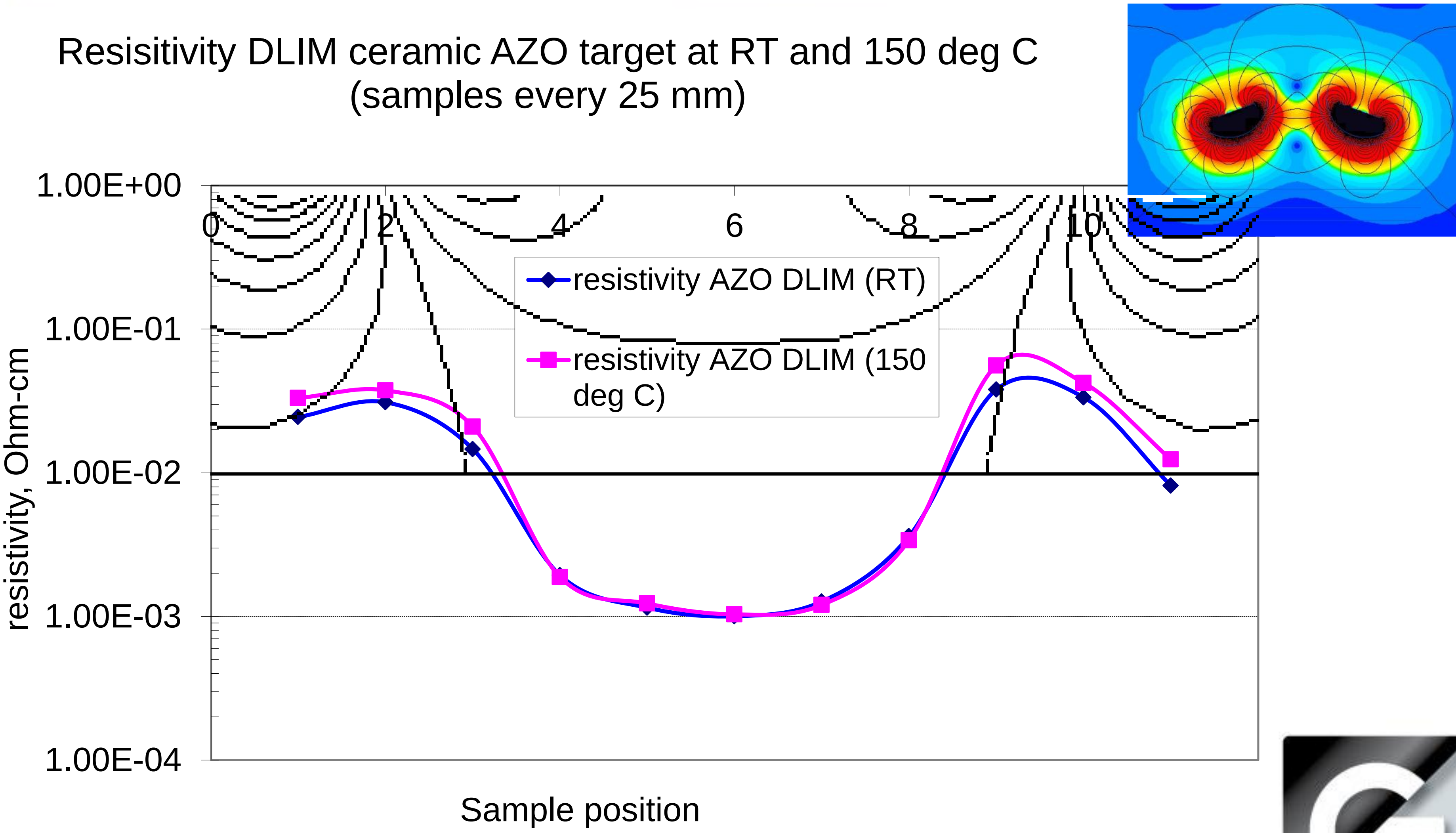
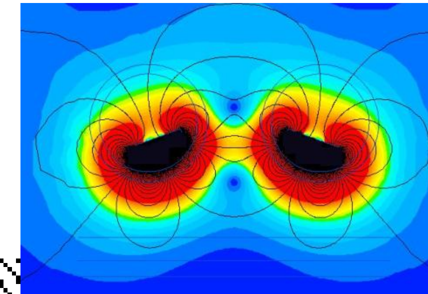
Comparison of BOC AZO resistivity against DLIM AZO resistivity at room temperature



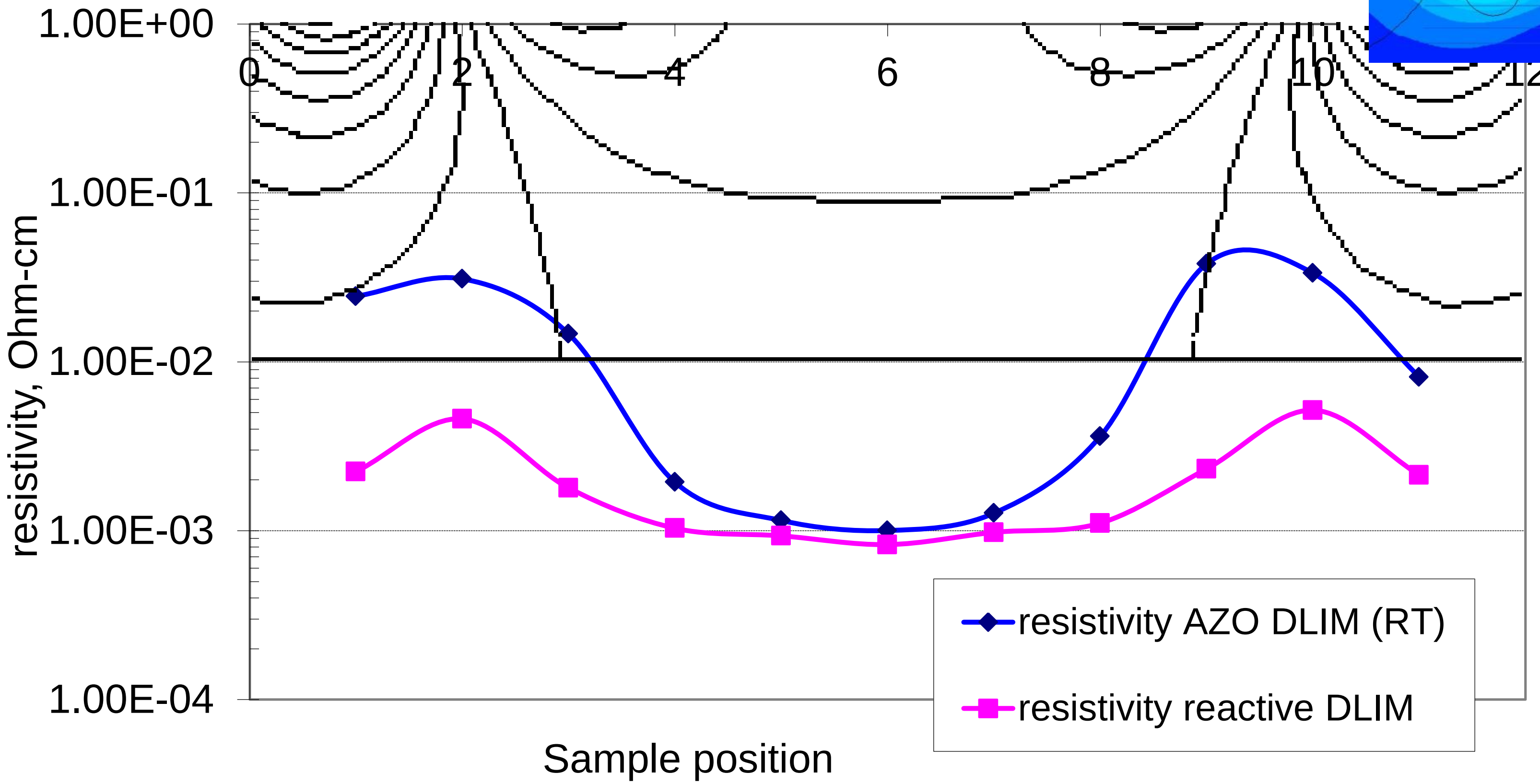

Resisitivity DLIM ceramic AZO target at RT and 150 deg C
(samples every 25 mm)
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
0
2
4
6
8
10
resistivity AZO DLIM (RT)
resistivity AZO DLIM (150 deg C)
resistivity, Ohm-cm
Sample position

Comparison of electrical properties for ceramic and DLIM for optimized layers

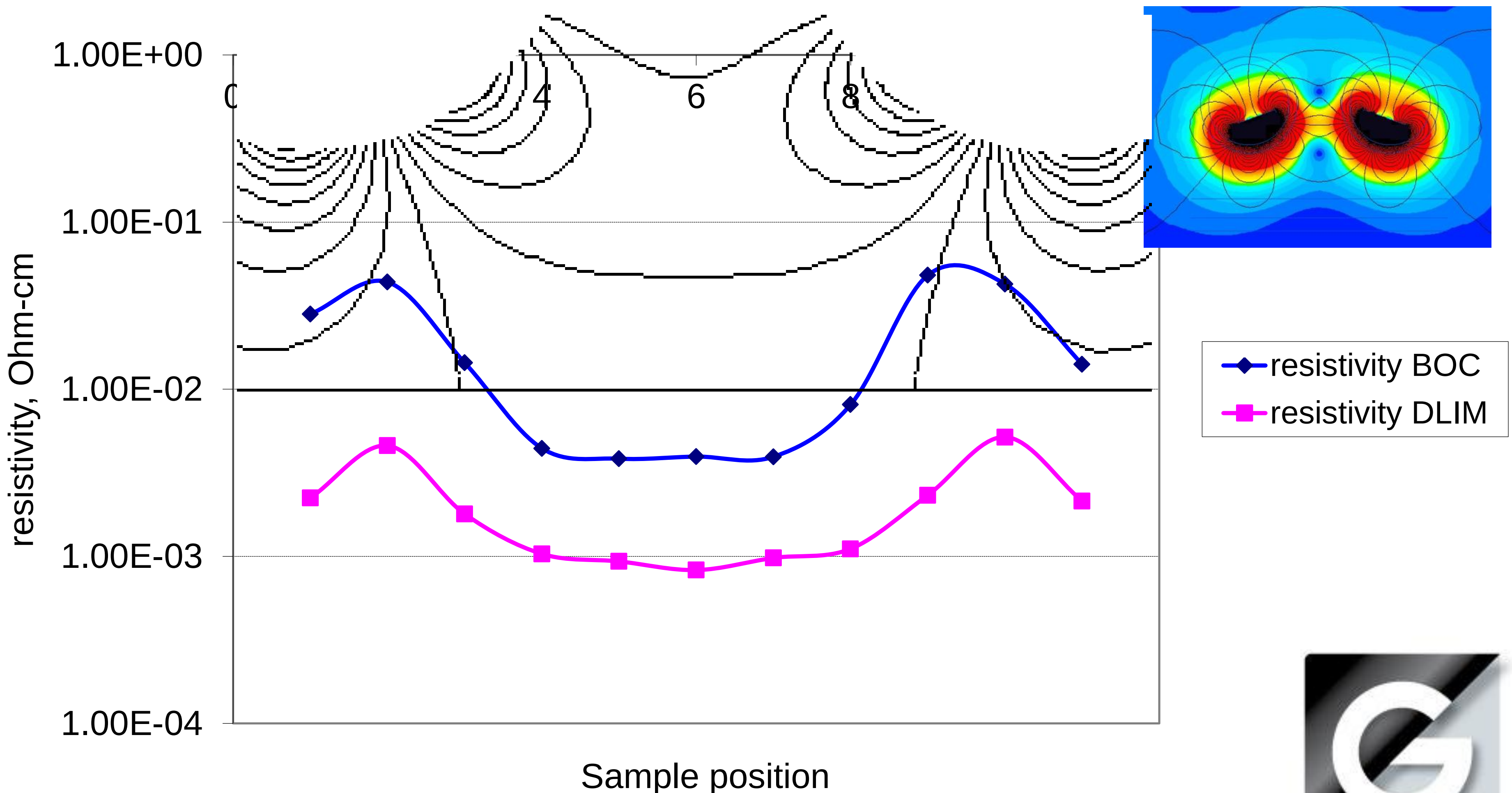
without substrate heating and with AC power



Resisitivity DLIM (reactive and ceramic AZO) at room temperature (static coating every 25 mm under double magnetron cathodes)



Resisitivity BOC & DLIM at room temperature (every 25 mm)



$AZ+O_2$ film properties at Room Temperature and 150ºC with similar properties

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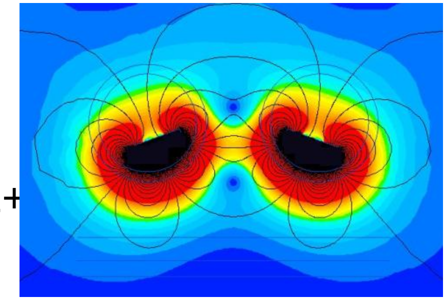
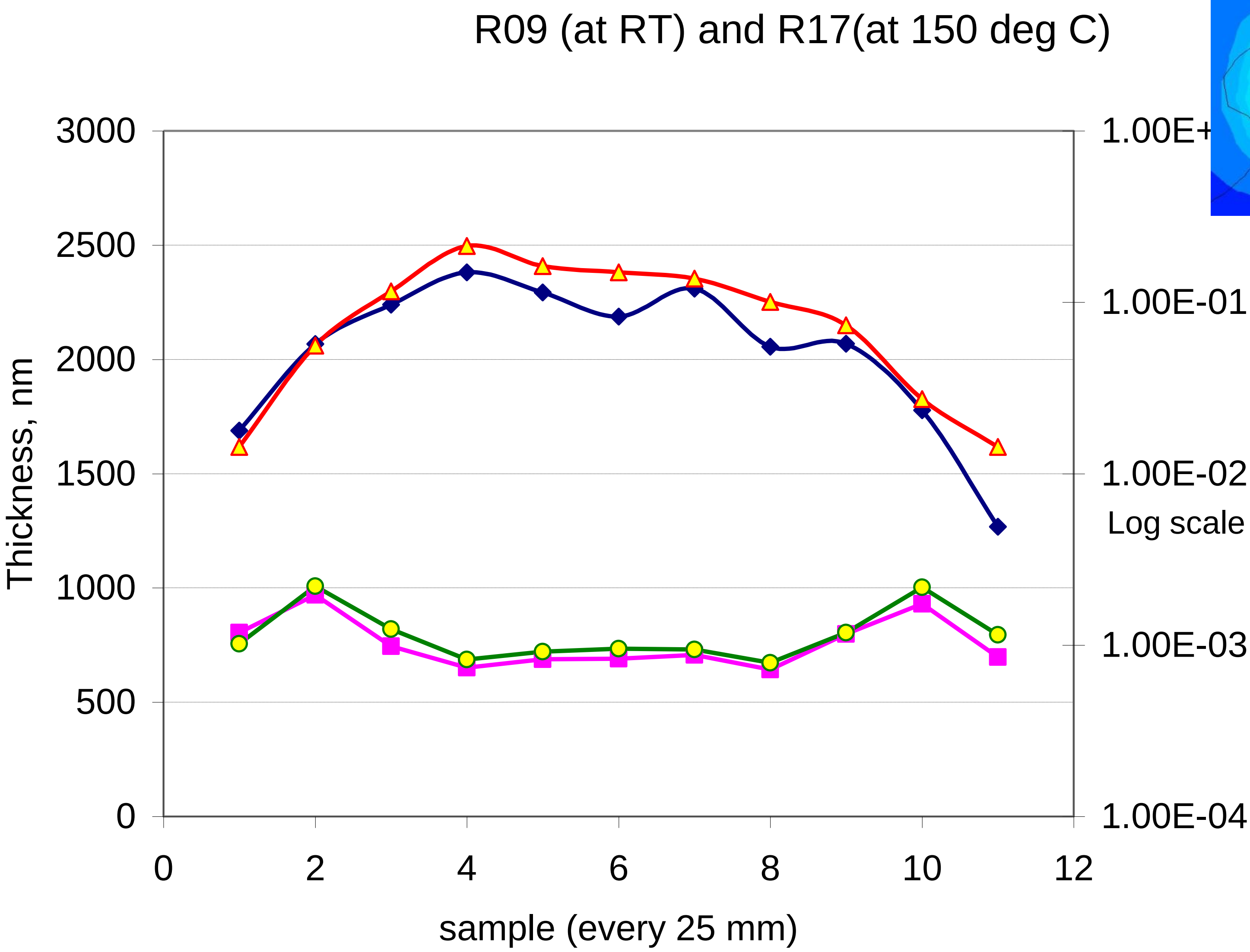
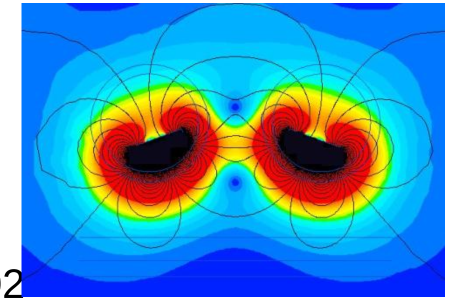
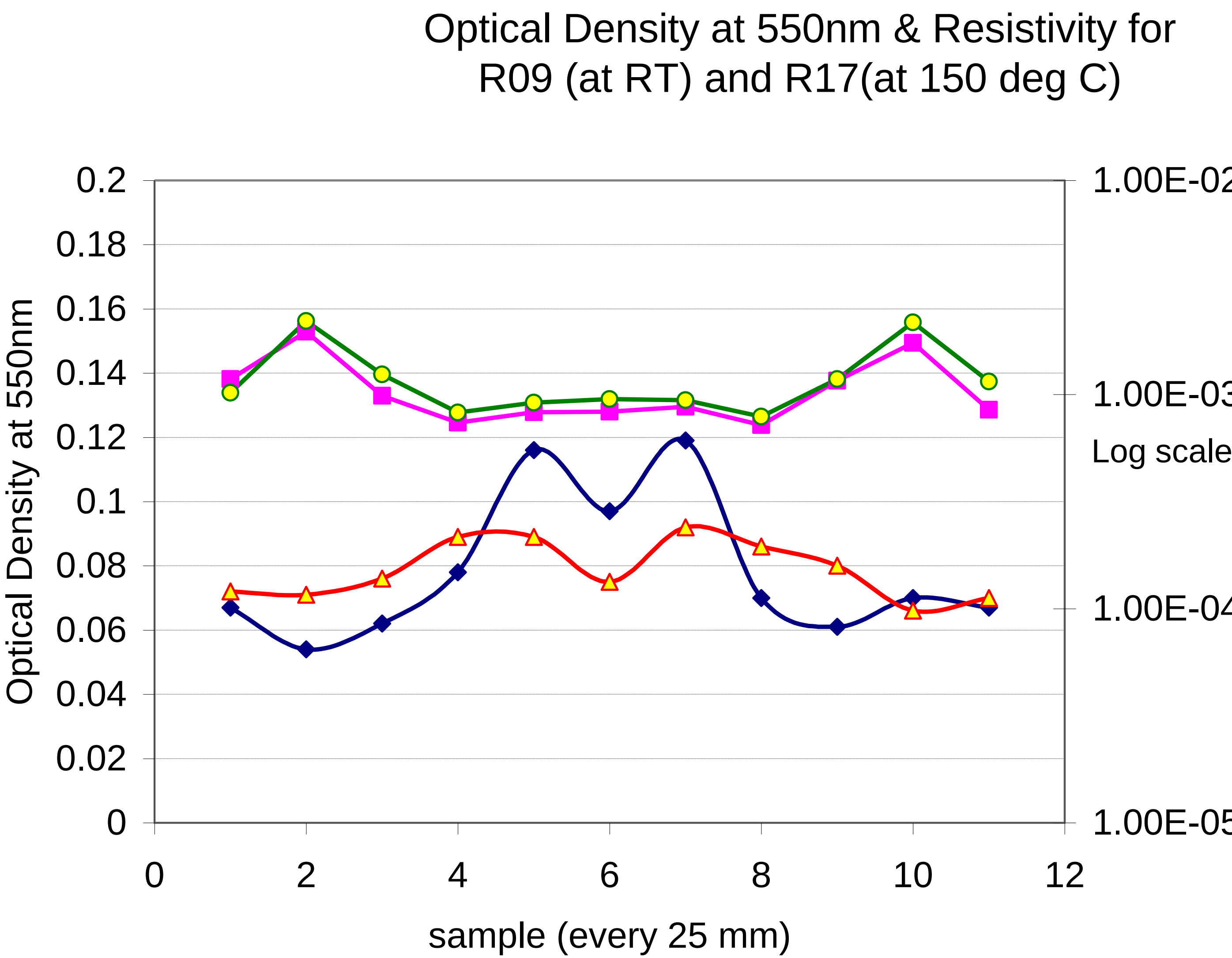


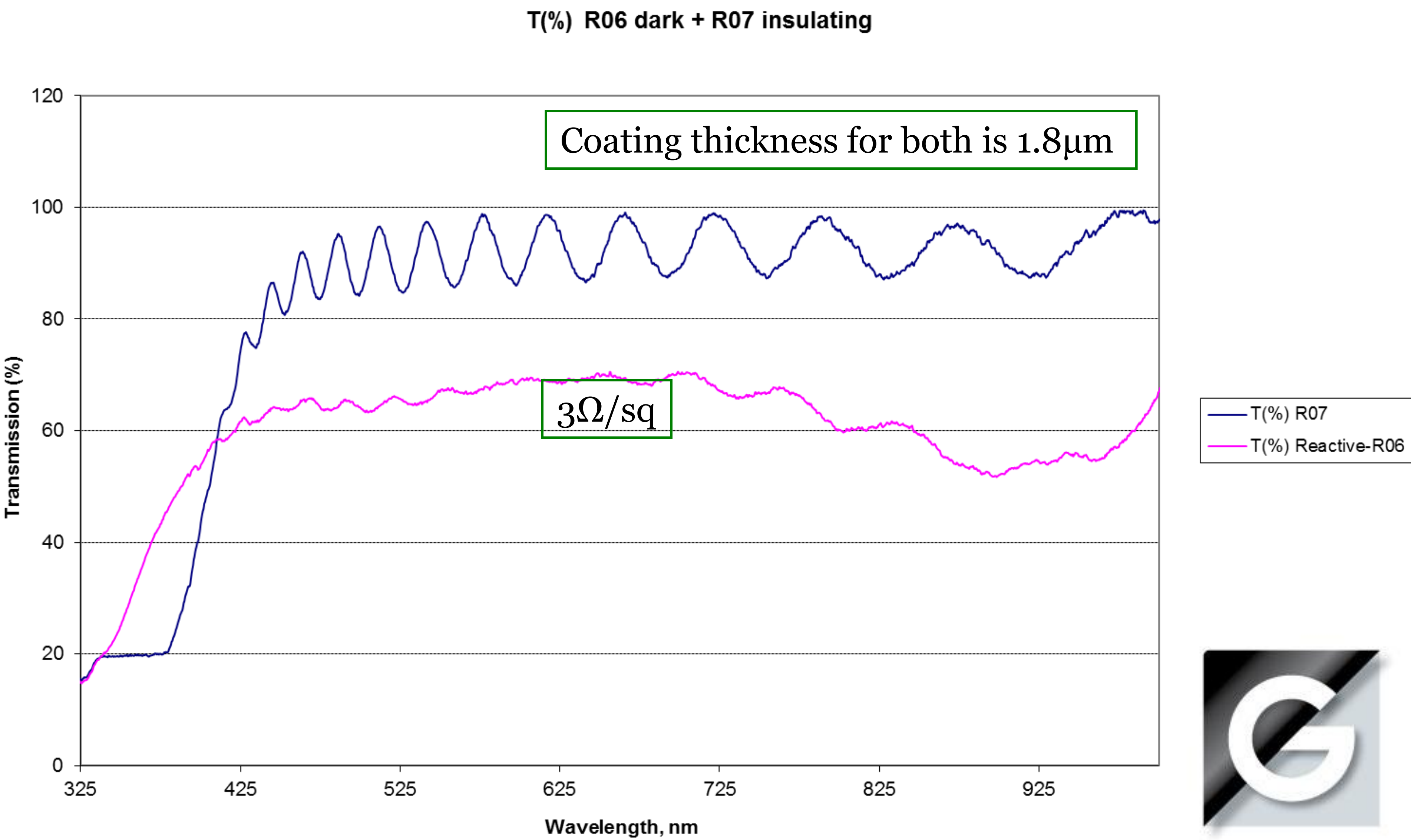


Room temperature films have better optical density with DLIM magnetics

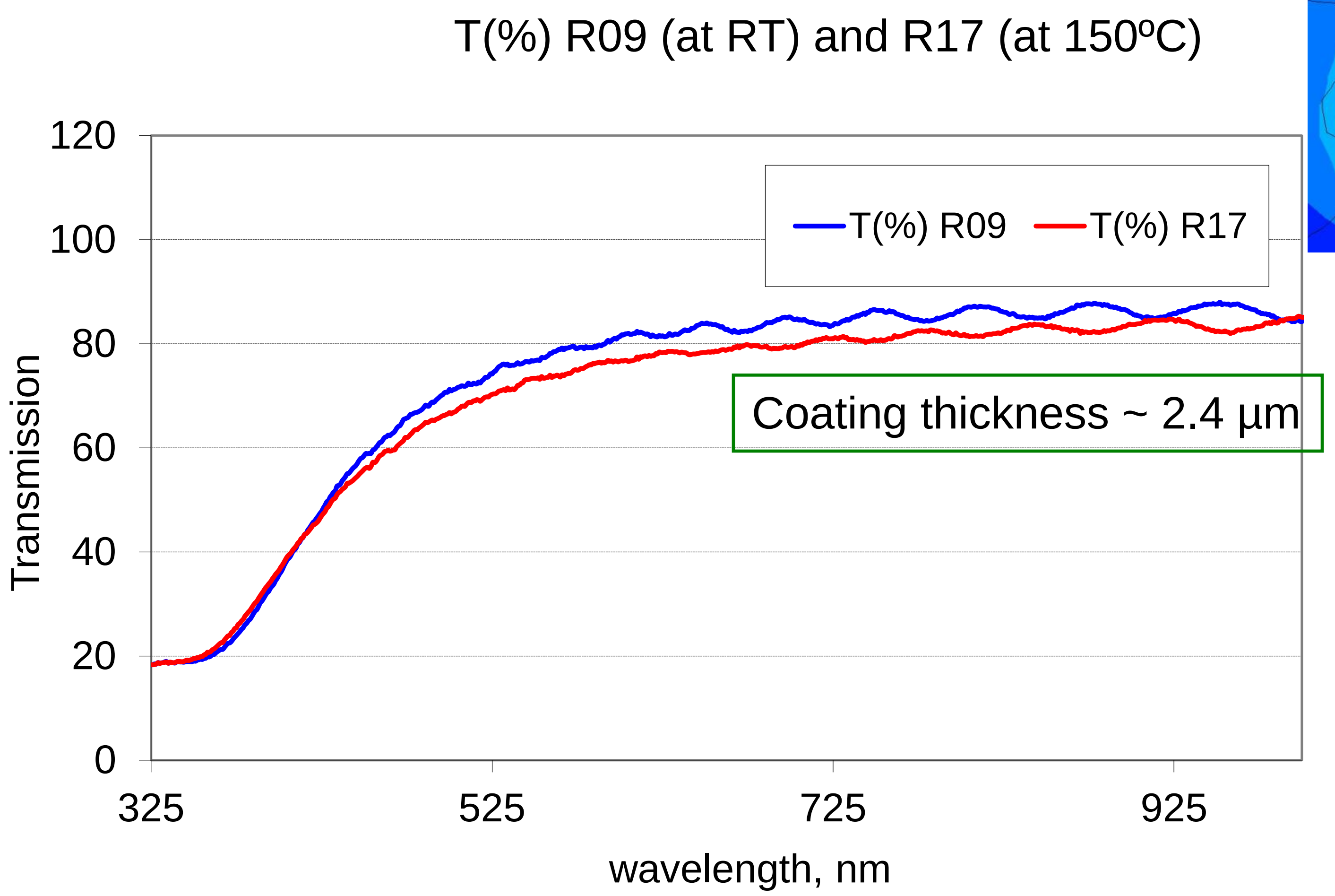


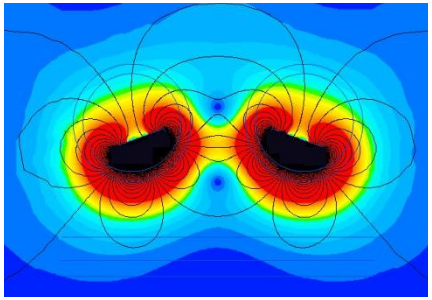


With reactive processes transmission can tuned over a wide range and tuned with electrical properties for different applications

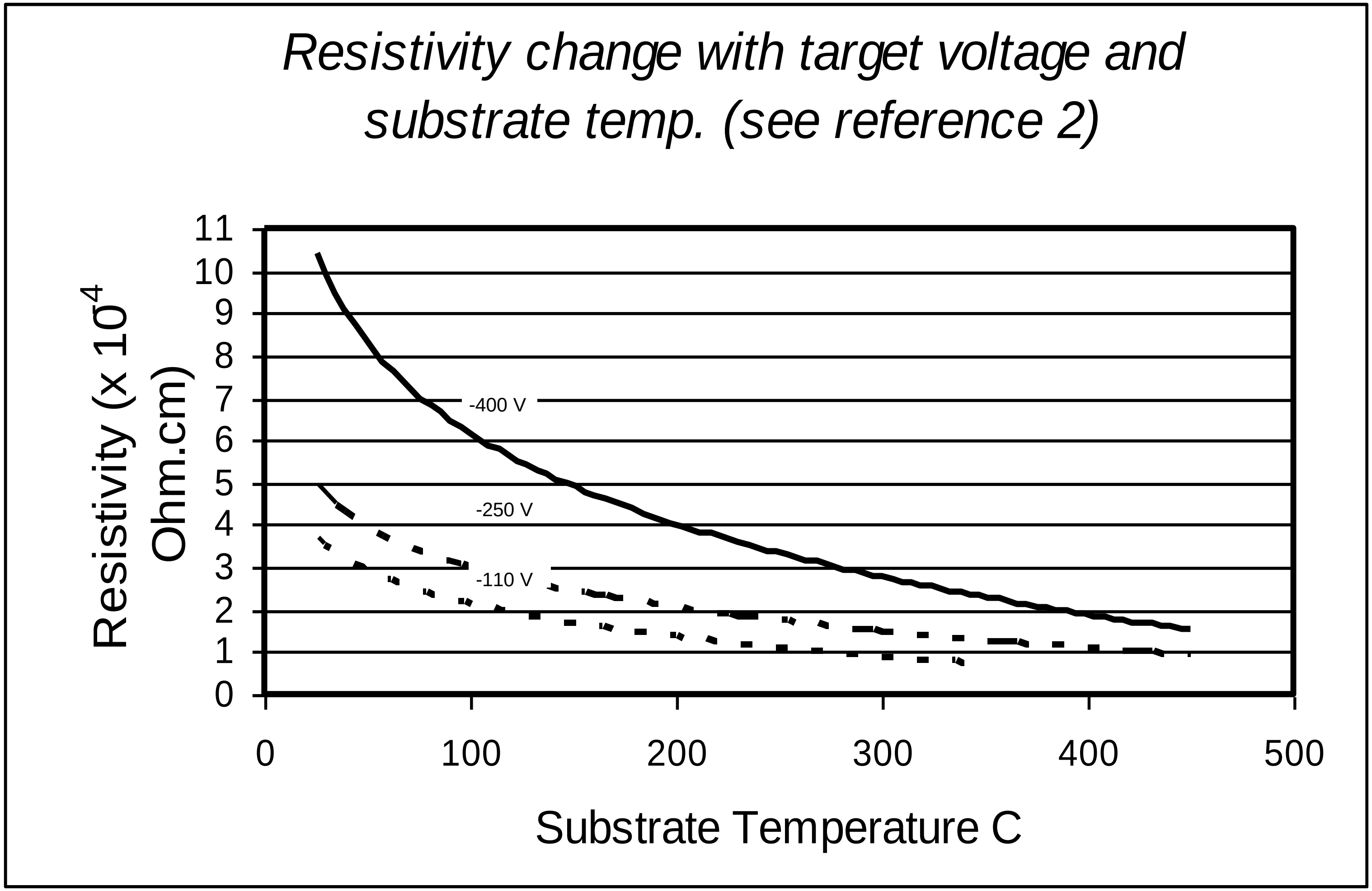


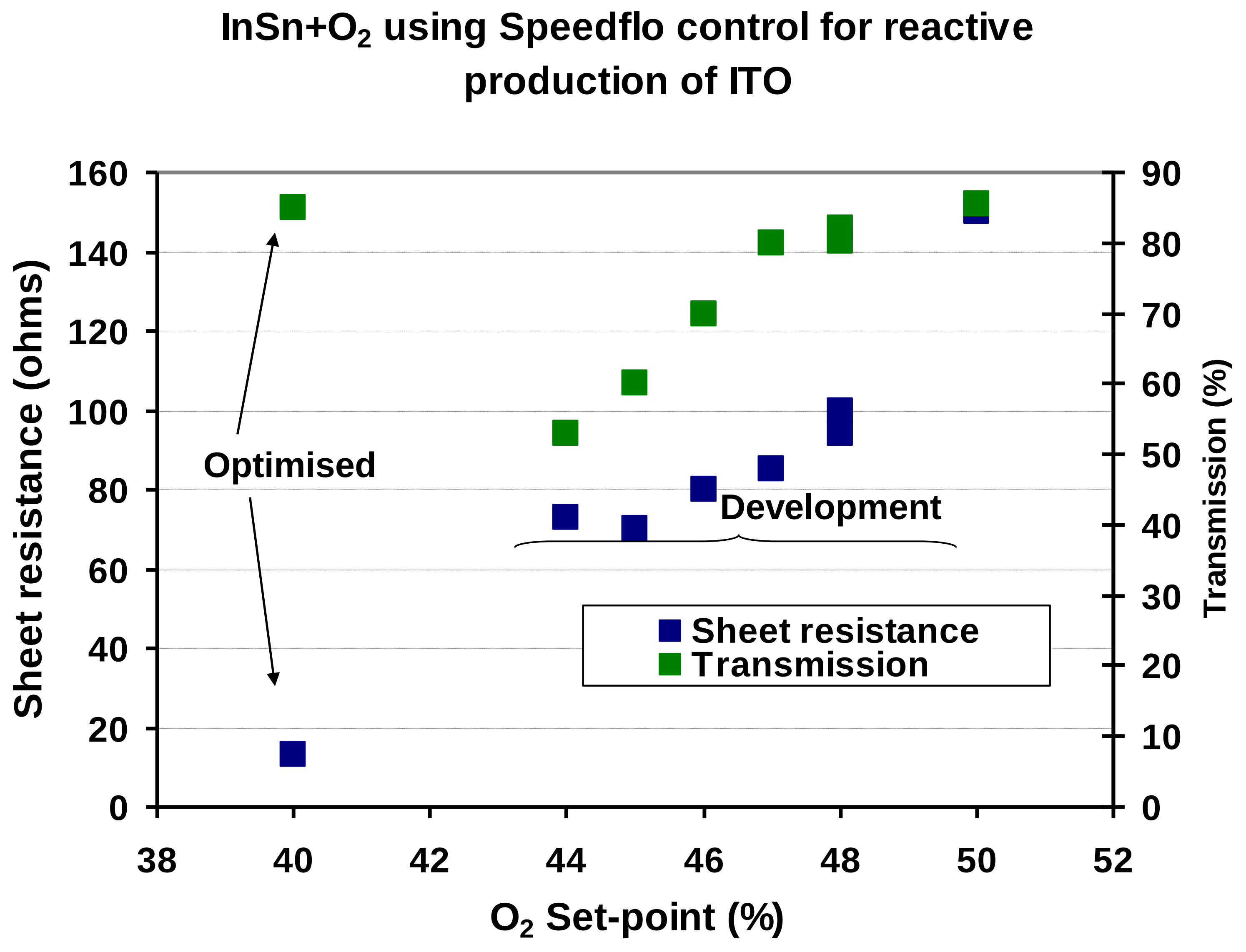
AZ+O_2 transmittance in the visible spectrum good low temp transparency



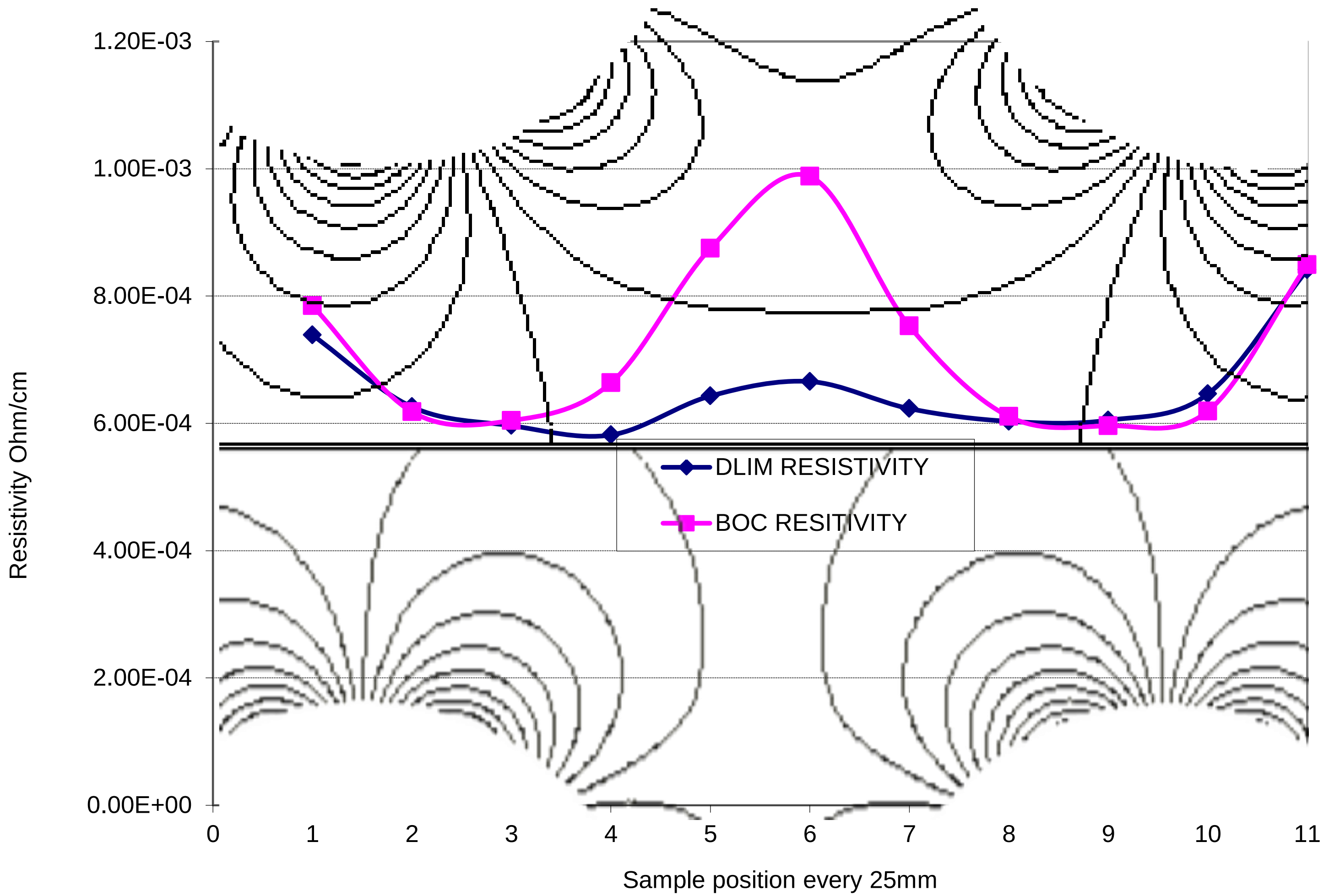


Crystal structure and doping is critical for all TCO's

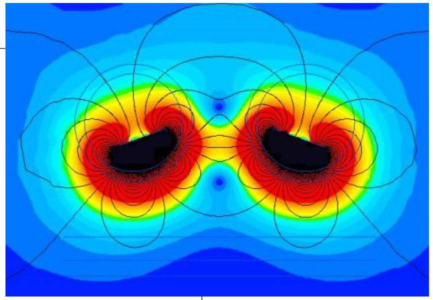


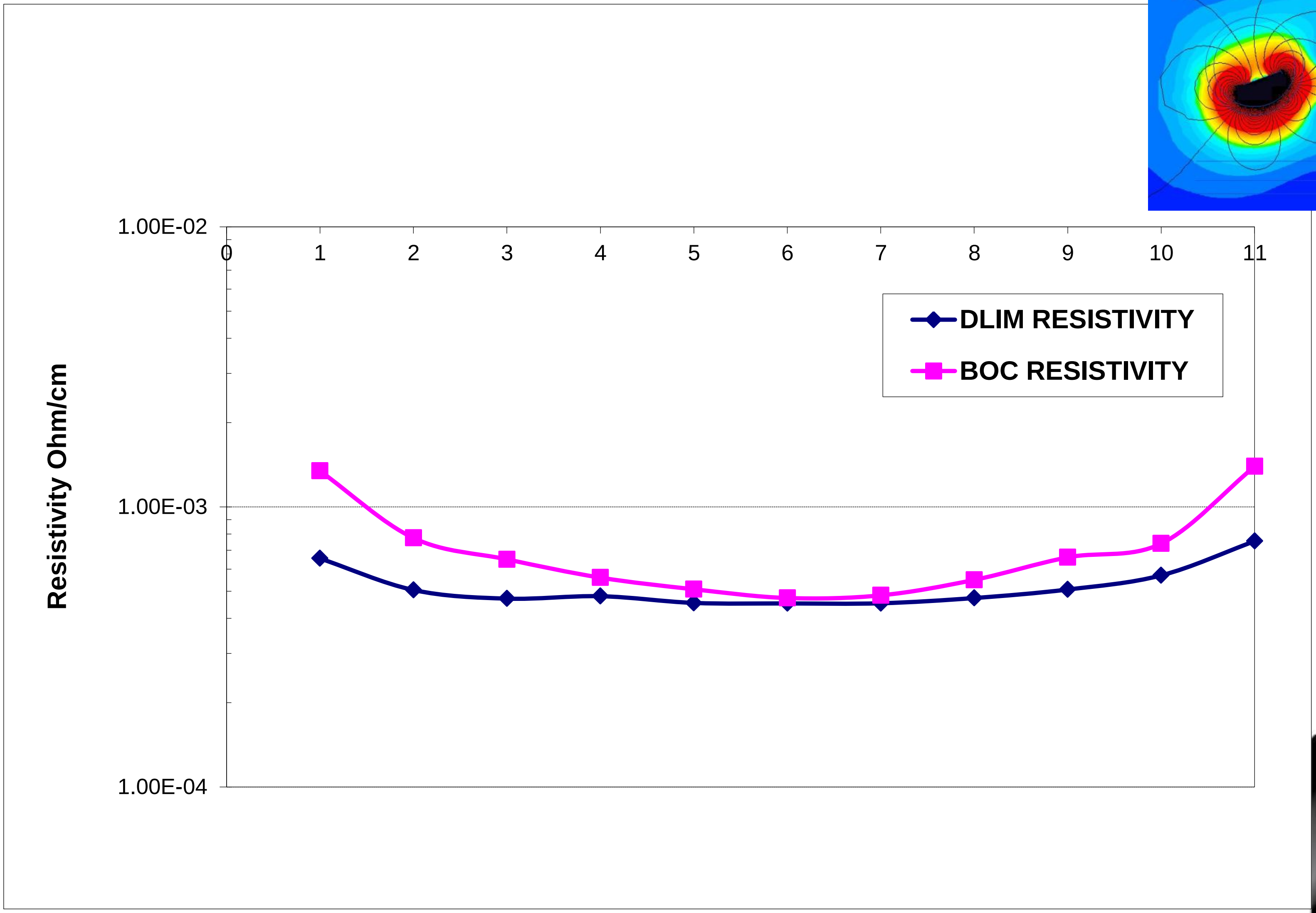

InSn+O2 using Speedflo control for reactive production of ITO
Sheet resistance (ohms)
Transmission (%)
O2 Set-point (%)
Optimised
Development
Sheet resistance
Transmission
0
20
40
60
80
100
120
140
160
10
30
50
70
90
38
42
44
46
48
50
52

Reactive ITO comparison of conventional magnetic design and DLIM with AC power mode



Reactive ITO comparison of conventional magnetic design and DLIM with AC power mode at 150°C





Reactive ITO with DLIM, AC power mode and varying substrate temperature

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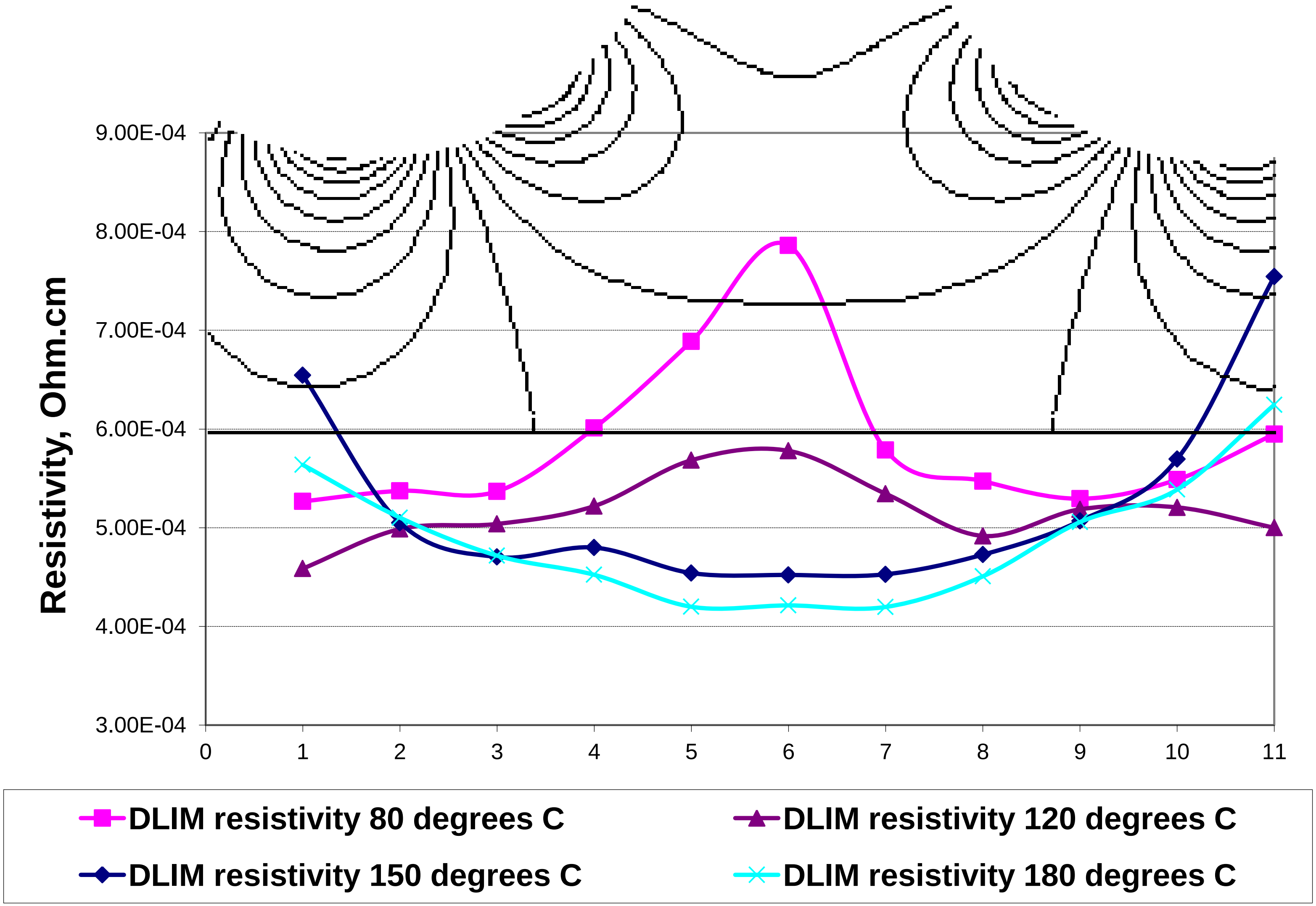
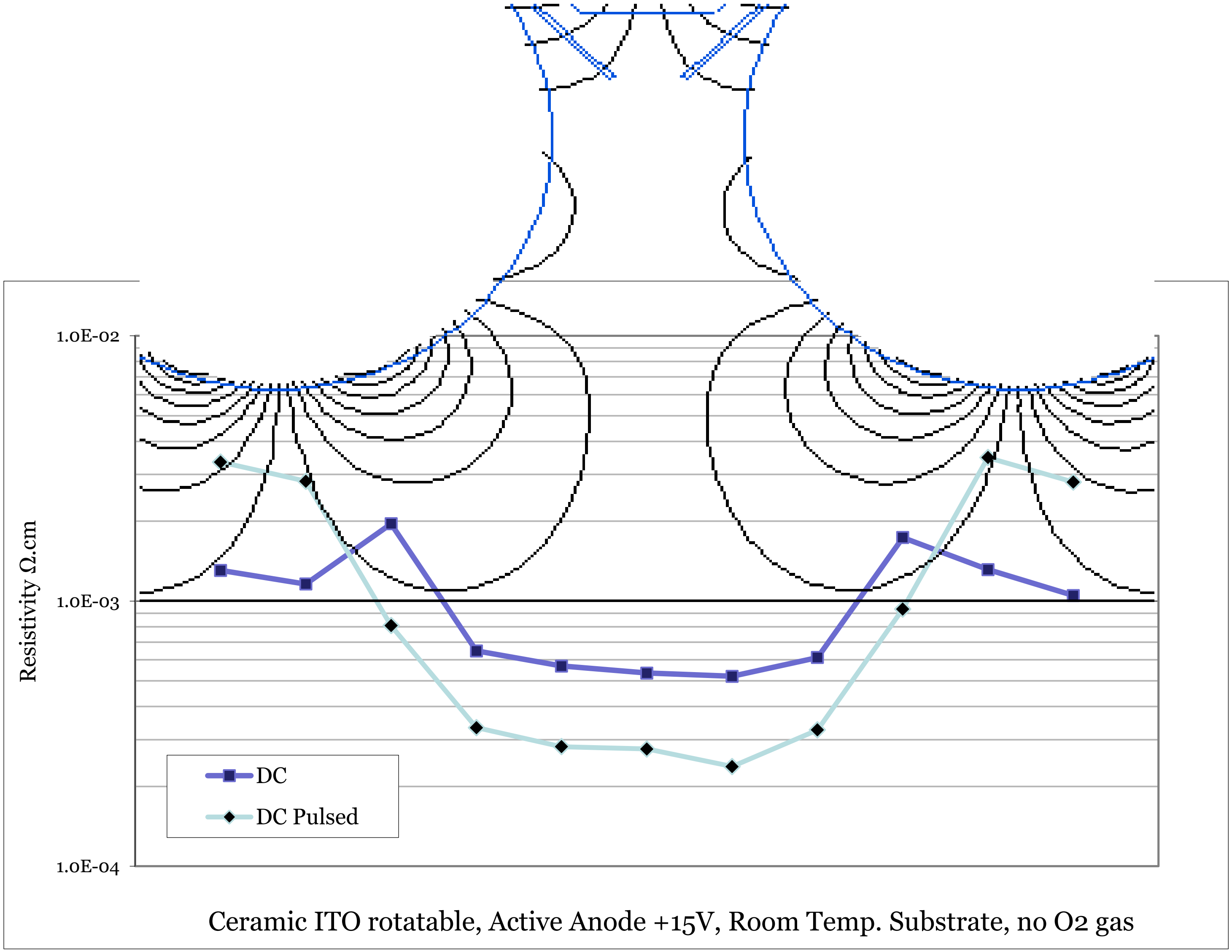
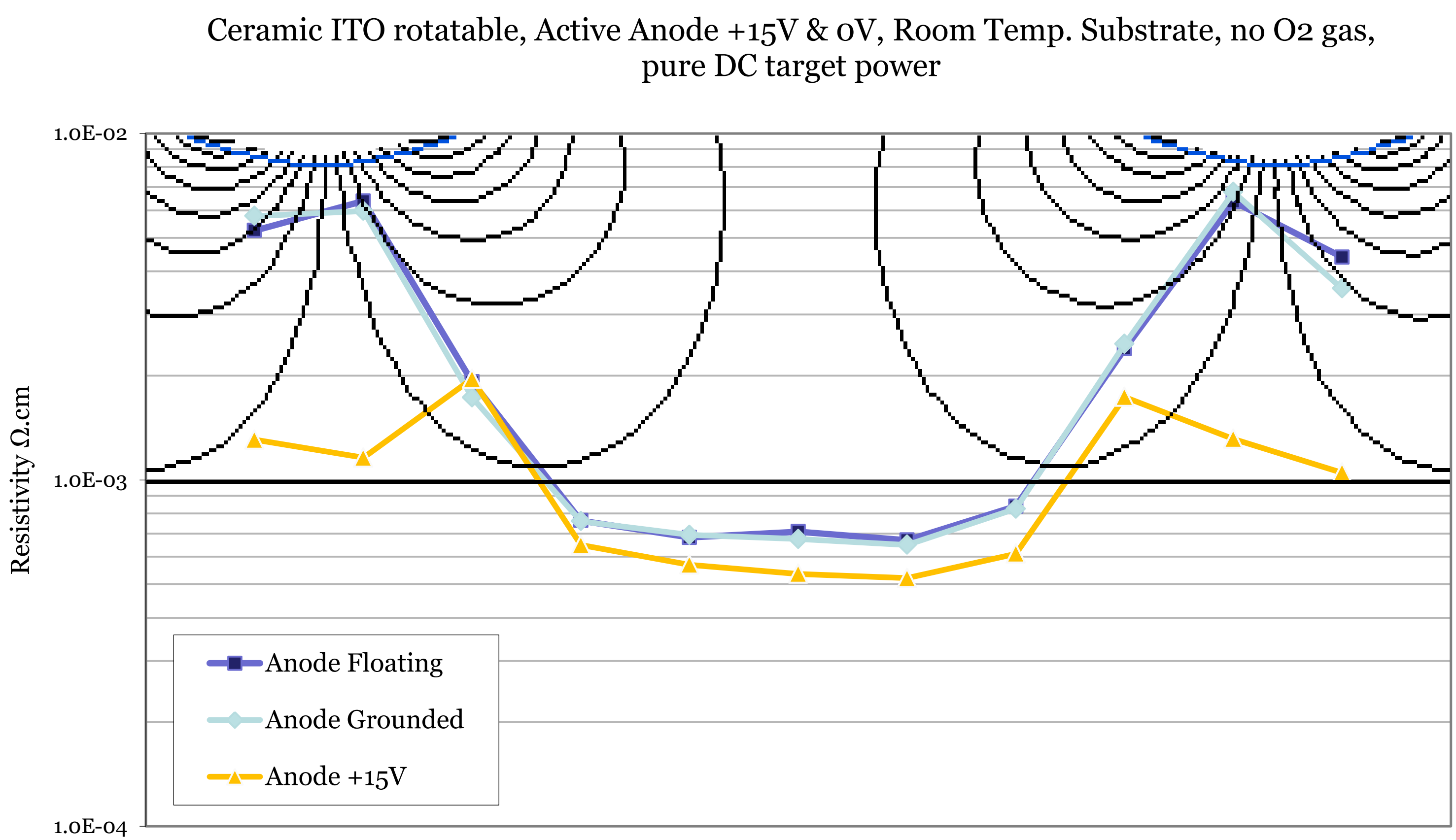


- For ITO from ceramic targets several process parameters affect the electrical conductivity of the ITO film:
  - Standard strength magnetics – 520 Gauss over target surface, average target voltage 370 Volts
  - Deposition power 2.5kW per target – 2 targets – total 5 kW
  - Target to substrate separation 10cm & 15cm
  - Deposition time 30 sec – static substrates
  - Average ITO film thickness 130-140nm
  - Ar & O2 gas flow – introduced at central and / or outer gas bars
  - Central magnetically guided anode varied from earthed, floating and +15 V.
  - Angle of the magnetic to the anode varied from 0, 30, 60 & 90°
  - Substrate temperature – RT 20°C, 180° C.

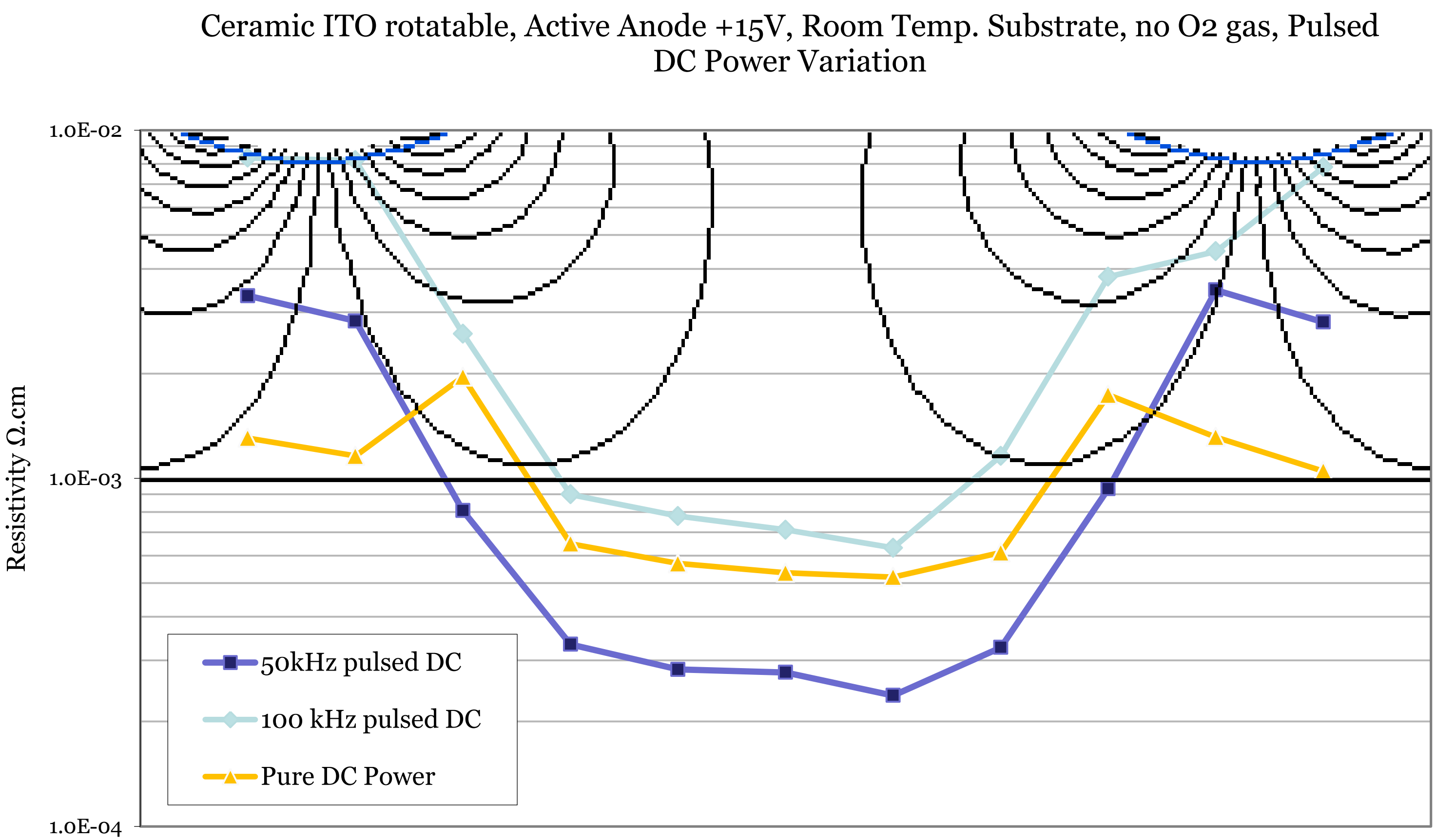
Ceramic ITO with DLIM – TCO (active anode, DC power mode and room temperature substrate (no heating)



Ceramic ITO with DLIM – TCO (active anode +15v, 0, floating, DC power and room temperature substrate (no heating)

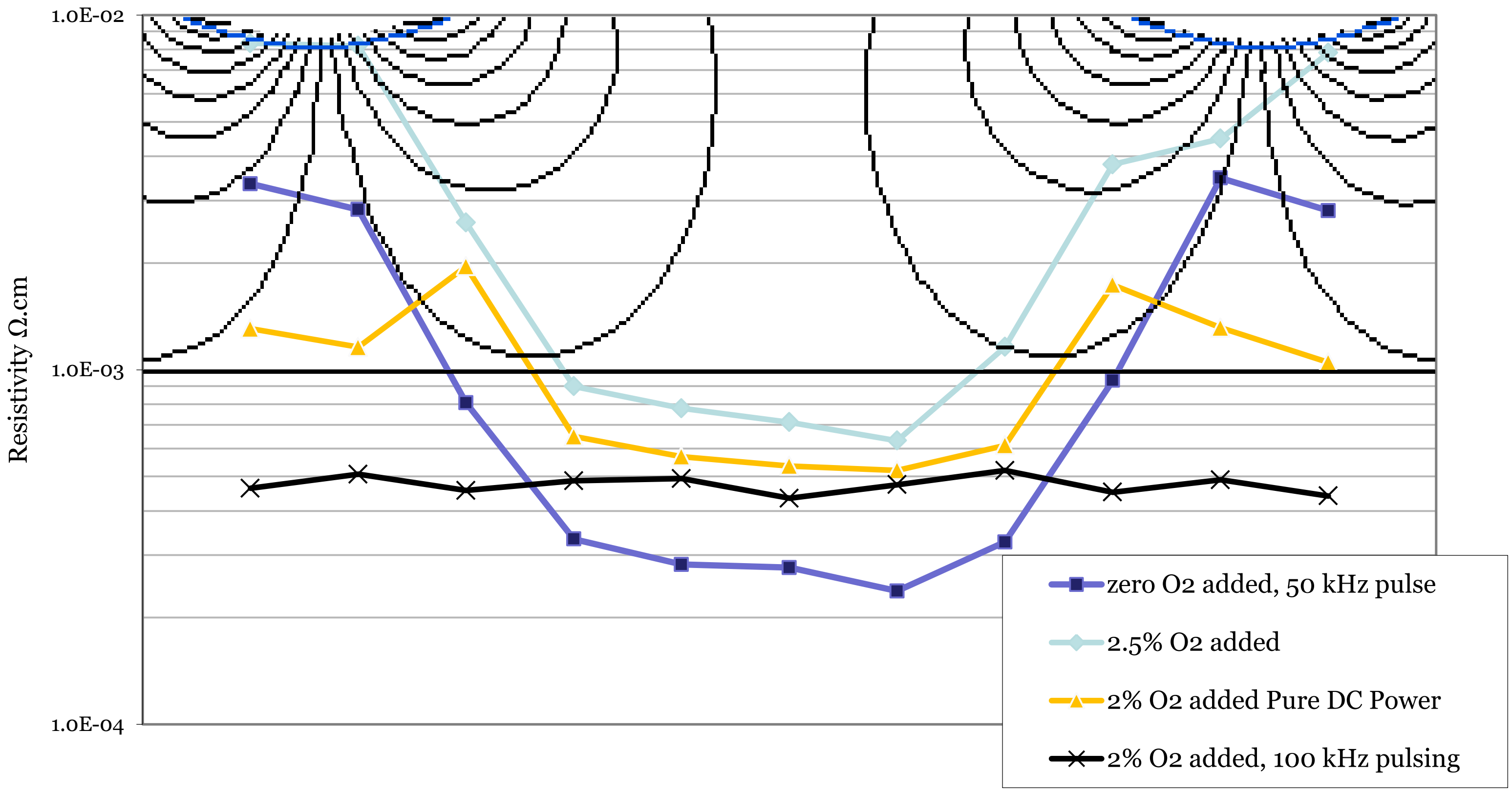


Ceramic ITO with DLIM – TCO (active anode +15v, varying DC modes and room temperature substrate (no heating)

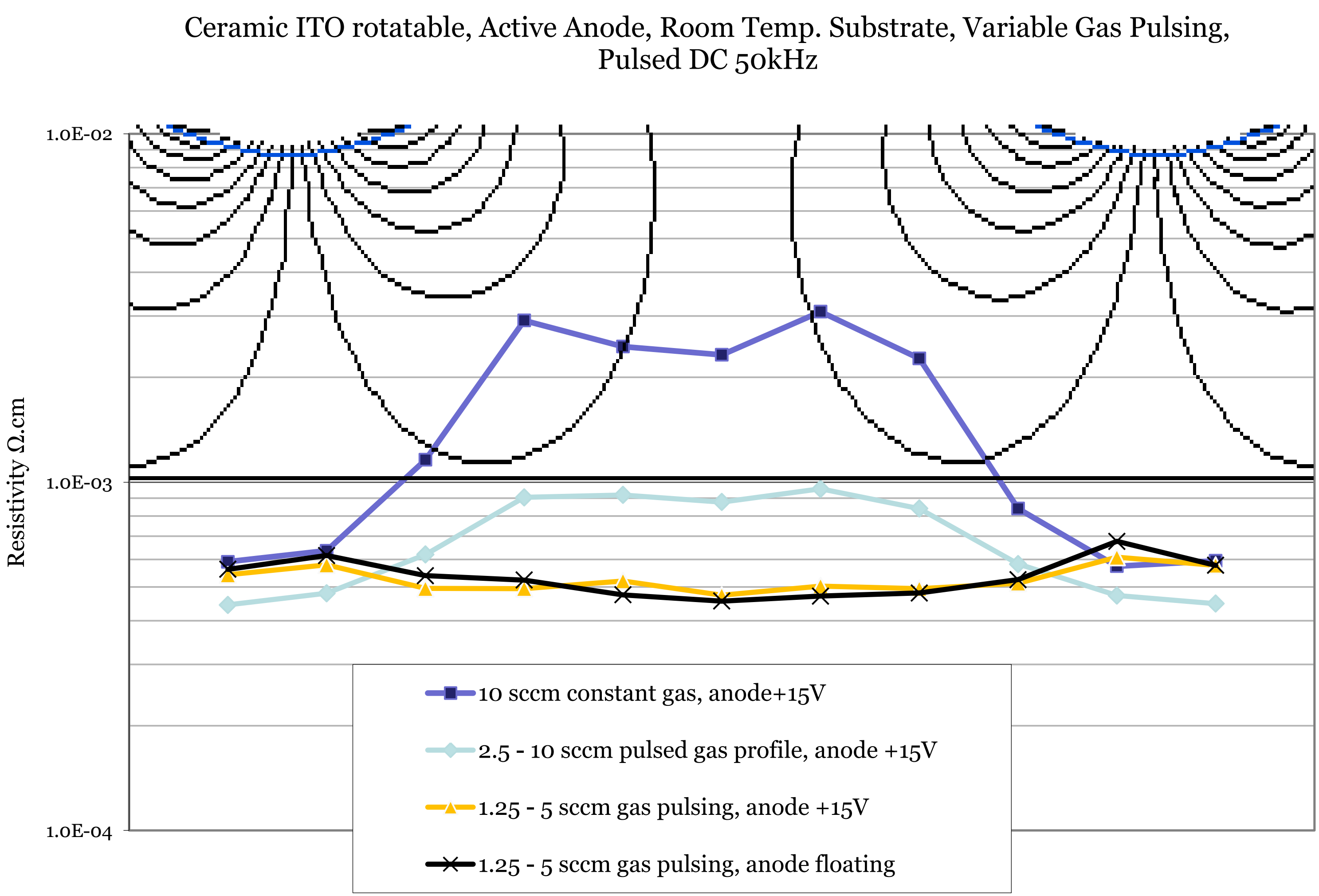


Ceramic ITO with DLIM – TCO (active anode +15v, DC power modes and varying gas mixtures (no heating)

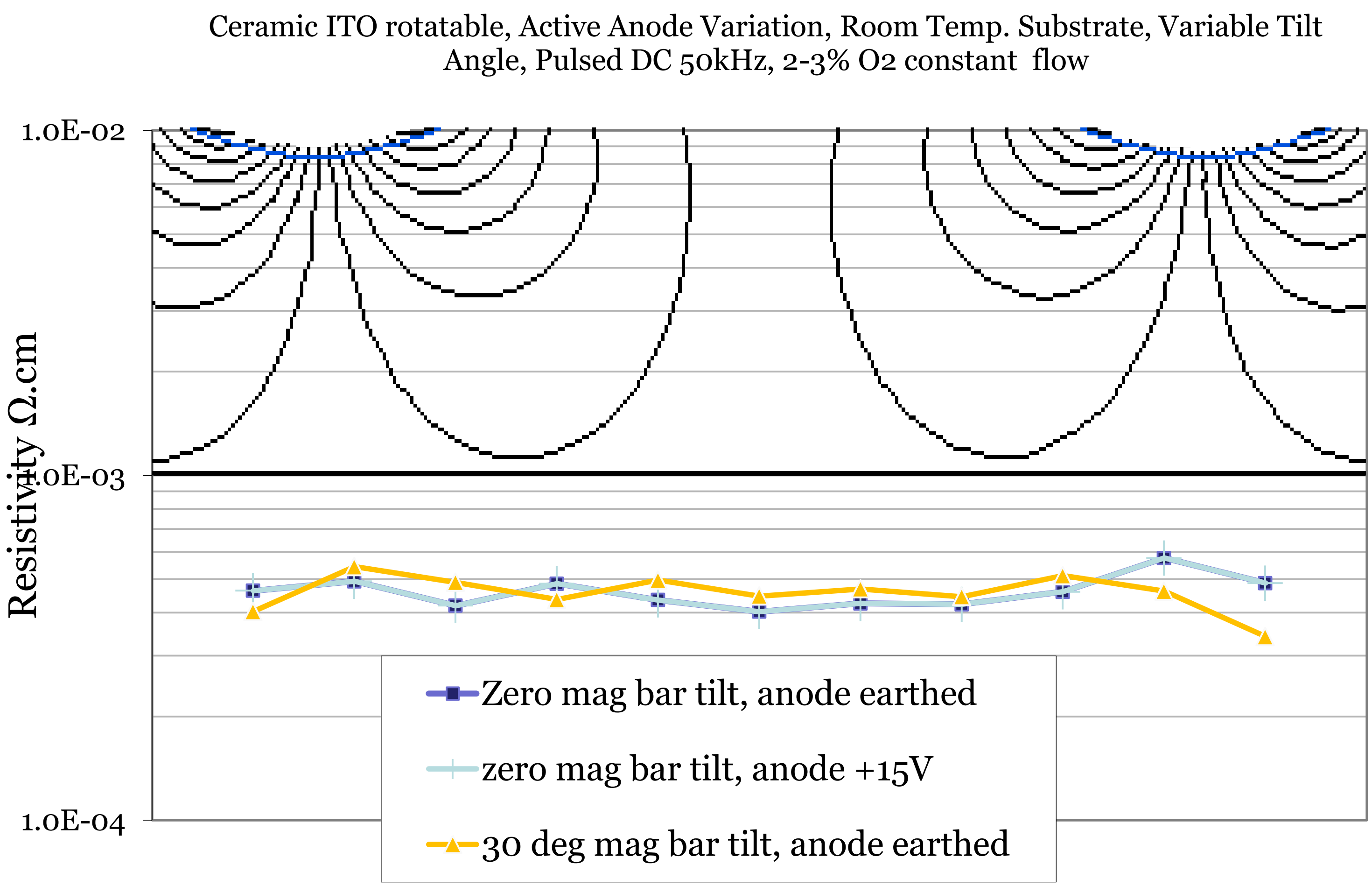
Ceramic ITO rotatable, Active Anode +15V, Room Temp. Substrate, no O2 gas, Pulsed DC Power Variation



Ceramic ITO with DLIM – TCO (active anode +15v & FL, DC 50kHz pulse and varying gas modes (no heating)



Ceramic ITO with DLIM – TCO (active anode +15v & 0v, DC 50kHz pulse and varying magnetics tilt angle (no heating)



Conclusions ITO Ceramic so far

• For ITO from ceramic targets several process parameters affect the electrical conductivity of the ITO film:

- Average resistivities of 5 x 10-3 to 4.6 x 10-4 Ω.cm can be achieved on room temperature substrates depending upon process parameters
- Power mode – 50kHz DC optimum compared to pure DC or 100kHz
- Gas Injection position – more tests needed for conclusions
- Anode Bias - +15V best but earthed also good
- O2 gas flow – optimum needed for transparency and electrical properties – gas pulsing can reduce resistivity peaks
- DLIM produces lower substrate heating
- DLIM TCO magnetics (with anode) lowers resistivity
- Under optimum conditions high resistivity peaks can be eliminated
- More tests are needed to achieve close to the best parameters and explore all possibilities

- For AC rotatable pairs the DLIM linked magnetic design improves the electrical properties of an AZO based TCO for both ceramic and reactive processing routes.
- Reactive AZO deposited from dual rotatable magnetrons can be readily tuned over a wide range and all have much lower internal stress than the ceramic approach.
- Reactive AZO deposited with DLIM and MF power show equally good or better properties at without substrate heating when compared to elevated temperatures allowing high quality deposition onto temperature sensitive substrates and energy savings.
- Reactive ITO is optimised with DLIM magnetics and elevated substrate temperatures with a plasma interaction effect varying with temperature.
- Reactive ITO displays low resistivity with AC power

- Special thanks to Heraeus for providing AZO and Zn:Al targets and to the Indium Corporation of America for the In:Sn target.