Evaluation of Multipactor Suppression in Dielectric Accelerators By DLC coating

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History of Discovery of Multipactor in Dielectric accelerators

First discovery of Multipactor in dielectric accelerators (R.B. R.-Shersby-Harvie, *et al., Proc. I.E.E.* B., 104 (1957) 273.)

It stated that Multipactor cured by **degreasing** structure and replacing oil pump with **mercury pump**.

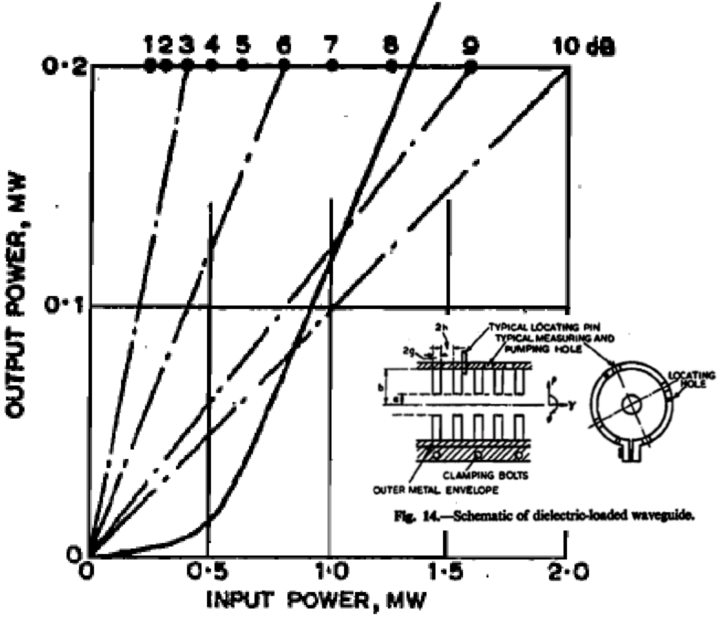
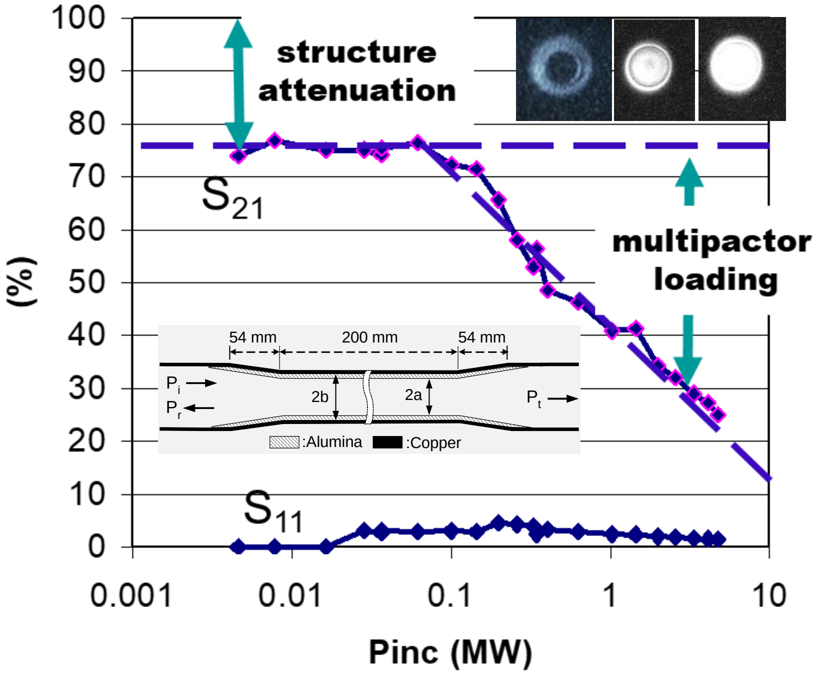


Fig. 14.—Schematic of dielectric-loaded waveguide.

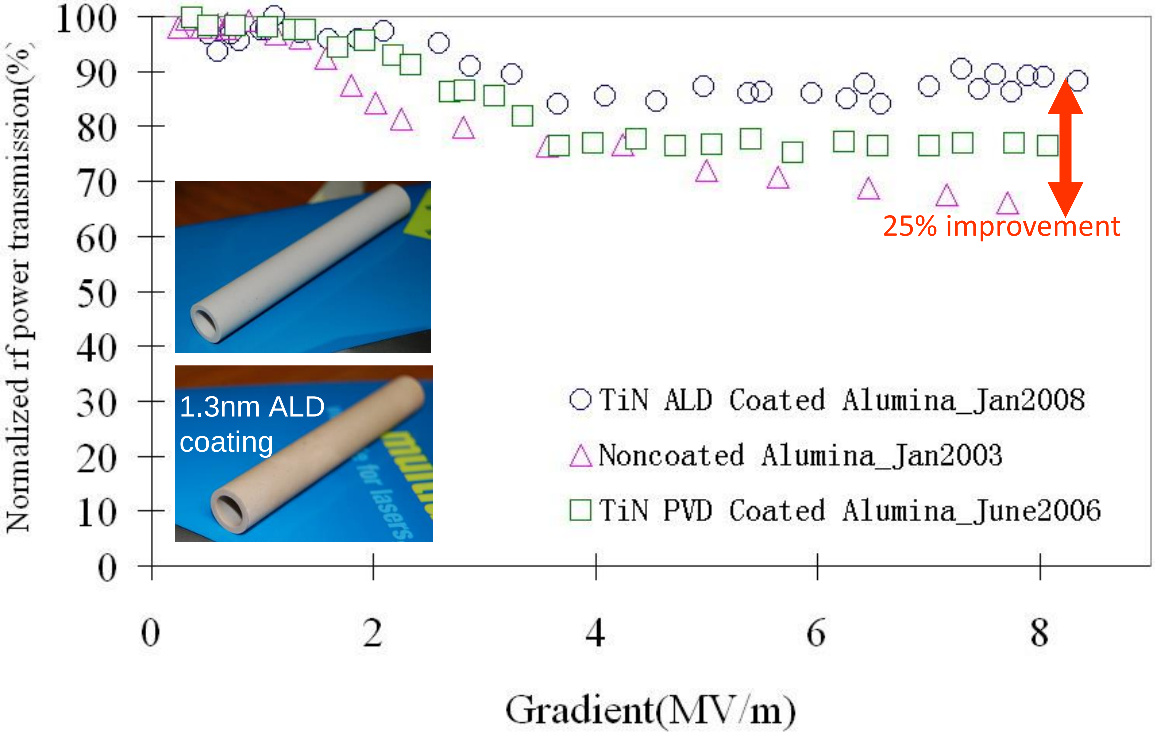
Fig. 25.—High-power attenuation.

Re-discovery of Multipactor in dielectric accelerators (J. G. Power, *et al*, *Phys. Rev. Lett*. 92, 164801 (2004).)

Tried variety of measures to suppress multipactor. Each of them has pros and cons.



History of Fighting Multipactor in Dielectric accelerators (I): TiN Coating

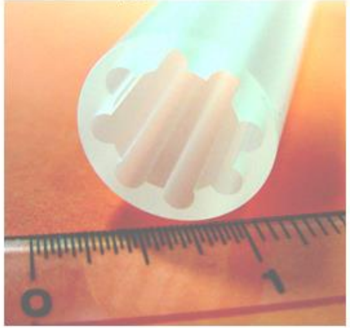


C. Jing, *et al.*, IEEE Trans. Plasma Sci. 38(6), 1354–1360 (2010).

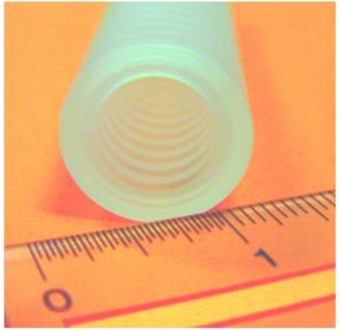
- Limited suppression on Multipactor
- Degrade over long time operation
- TiN coating is lossy, sensitive to the thickness
- TiN coating is vulnerable to the oxidation

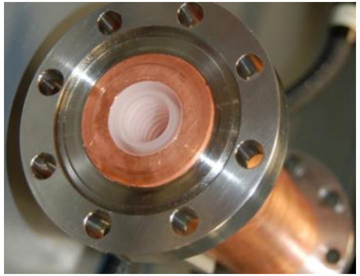
History of Fighting Multipactor in Dielectric accelerators (II): surface modification

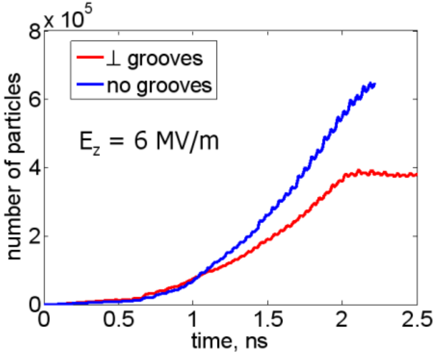
Longitudinal



Transverse







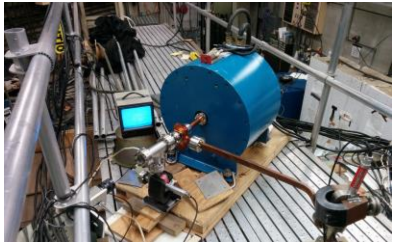
- introducing the fabrication complication.
- simulation shows its effectiveness, but no high power test being performed.
- effectiveness is sensitive the geometry

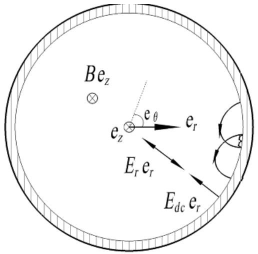
S. Antipov, et al, *Proc. PAC2011*, New York, NY, USA, pp.310-312.

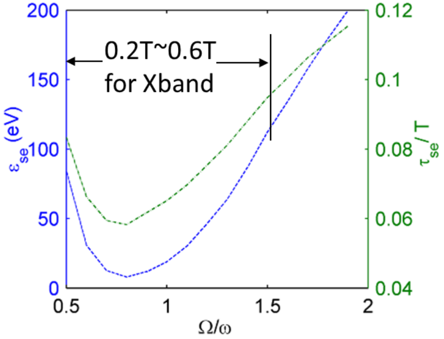
History of Fighting Multipactor in Dielectric accelerators (III): solenoid

Principle: the introduced Bz can effectively alter the transit time τ of secondary electrons. A proper strength of Bz makes τ in the range of (T/2,T) so that Er is always pushing electrons back to the dielectric surface, leading to a very small impact energy, then SEE<1.

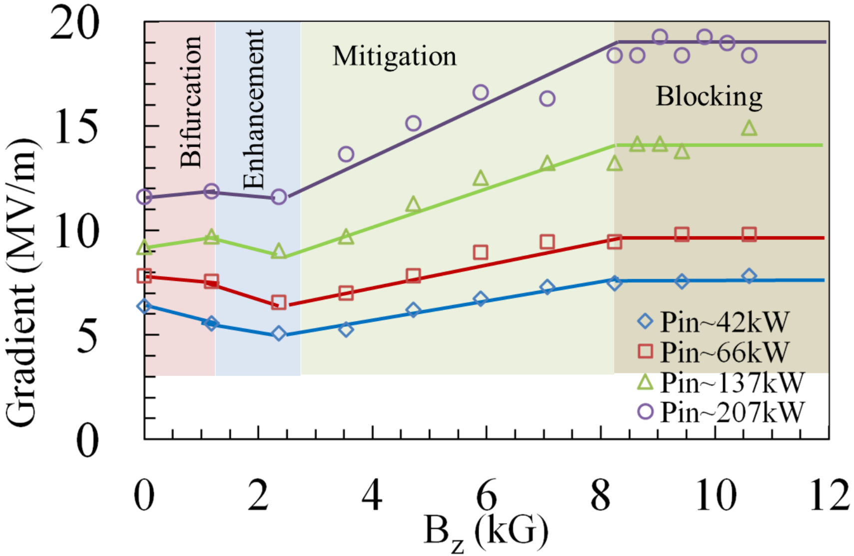
- Very bulky because of the high demanding of the solenoid strength.
- Not feasible for high gradient structures





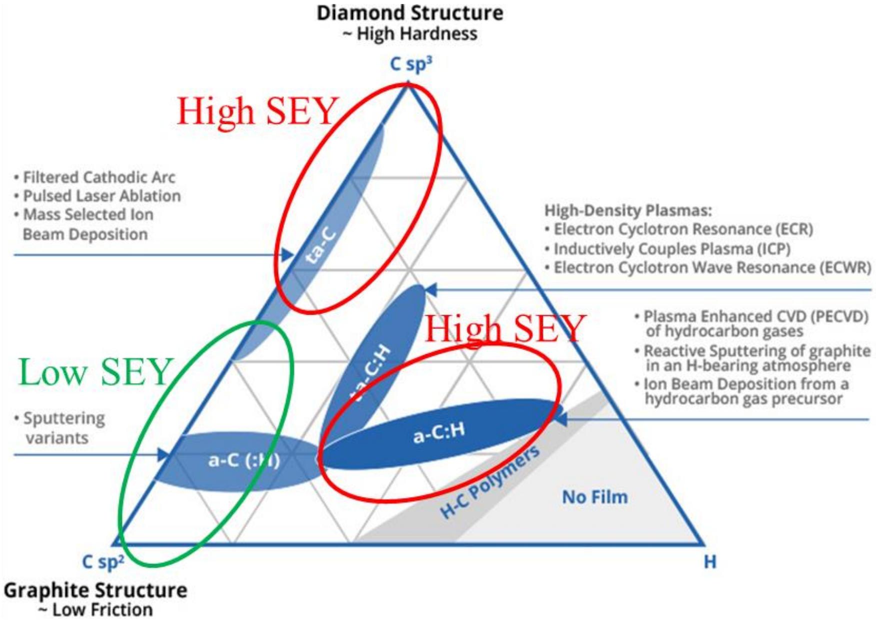


•C. Chang, et al, *J. Appl. Phys.* **110**, 063304 (2011).

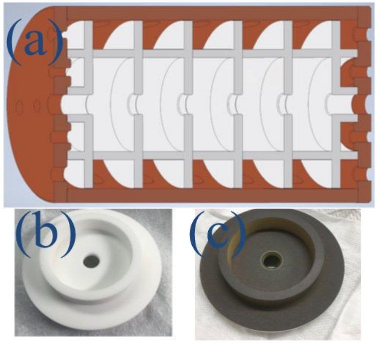


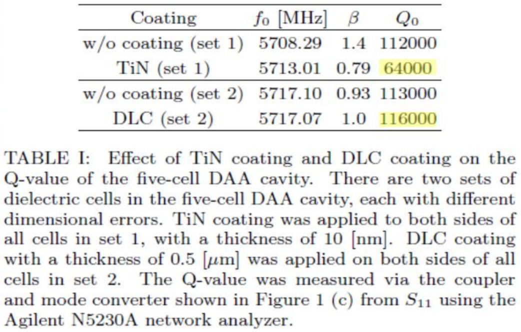
•C. Jing, *et al*, *Appl. Phys. Lett.* 108, 193501 (2016)

New Method Fighting Multipactor in Dielectric accelerators: DLC coating



- 100% effective on Multipactor suppression.
- No impact on Q factor of the structure
- Good bonding on ceramic
- Mature technique in industrial applications to increase durability of machine tools.





Coating	f_0 [MHz]	β	Q_0
w/o coating (set 1)	5708.29	1.4	112000
TiN (set 1)	5713.01	0.79	64000
w/o coating (set 2)	5717.10	0.93	113000
DLC (set 2)	5717.07	1.0	116000

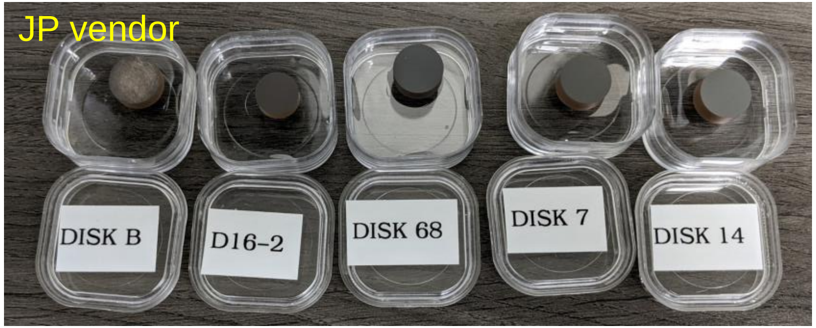
TABLE I: Effect of TiN coating and DLC coating on the Q-value of the five-cell DAA cavity. There are two sets of dielectric cells in the five-cell DAA cavity, each with different dimensional errors. TiN coating was applied to both sides of all cells in set 1, with a thickness of 10 [nm]. DLC coating with a thickness of 0.5 [μm] was applied on both sides of all cells in set 2. The Q-value was measured via the coupler and mode converter shown in Figure 1 (c) from S_{11} using the Agilent N5230A network analyzer.

•Pedro. Costa Pinto, *EIC2021 Accelerator Partnership Workshop*

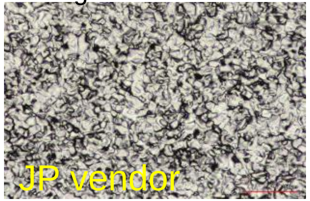
•Shingo Mori, *et al*, *Phys. Rev. Accel. Beams* 24, 022001, 2021

Investigating DLC coating at Euclid in Collaboration with CERN (I)

- No change of dielectric constant for all different materials.
- Other than high permittivity (eps~50) material, all other ceramics has improved loss tangent. Even for eps50 material, loss tangent<2e-4
- Surface resistance of all DLC coatings is above 1MΩ per □ and could not be measured with the using a Cylindrical four-point probe head from Jandel.
- We were in collaboration with CERN to get SEY measurement.

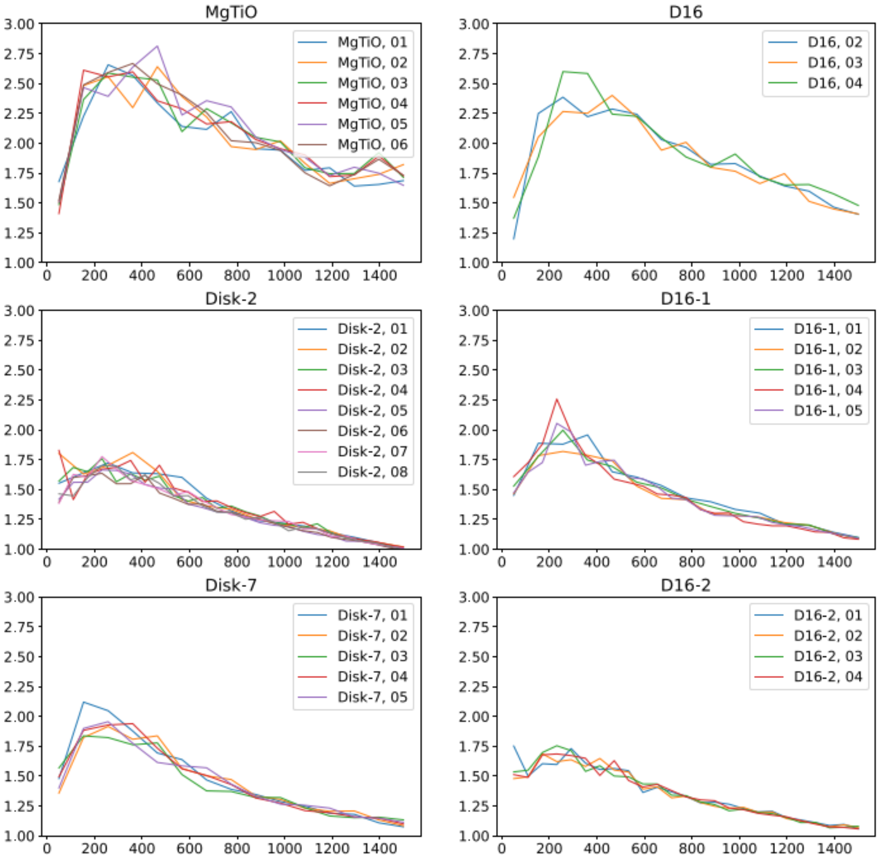


Roughness = 679nm

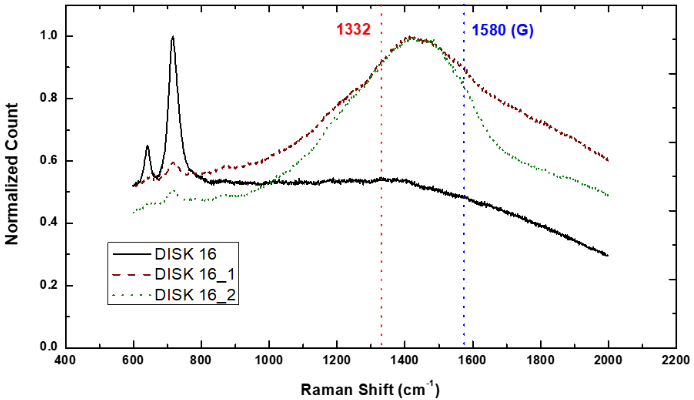


Roughness = 435nm

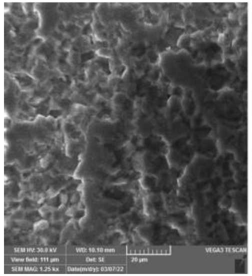
Investigating DLC coating at Euclid in Collaboration with CERN (II)



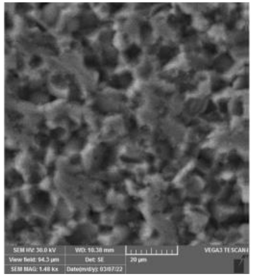
DLC films will always have sp^2 trigonal C-atoms. The quality of DLC films is given by the peak intensity ratio: I(1332):I$_G$. A high ratio (~ 4-5) indicates a high sp^3 diamond-like coating.



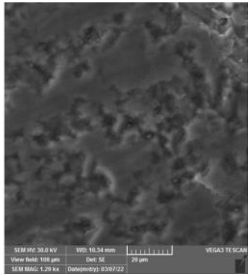
DISK 16



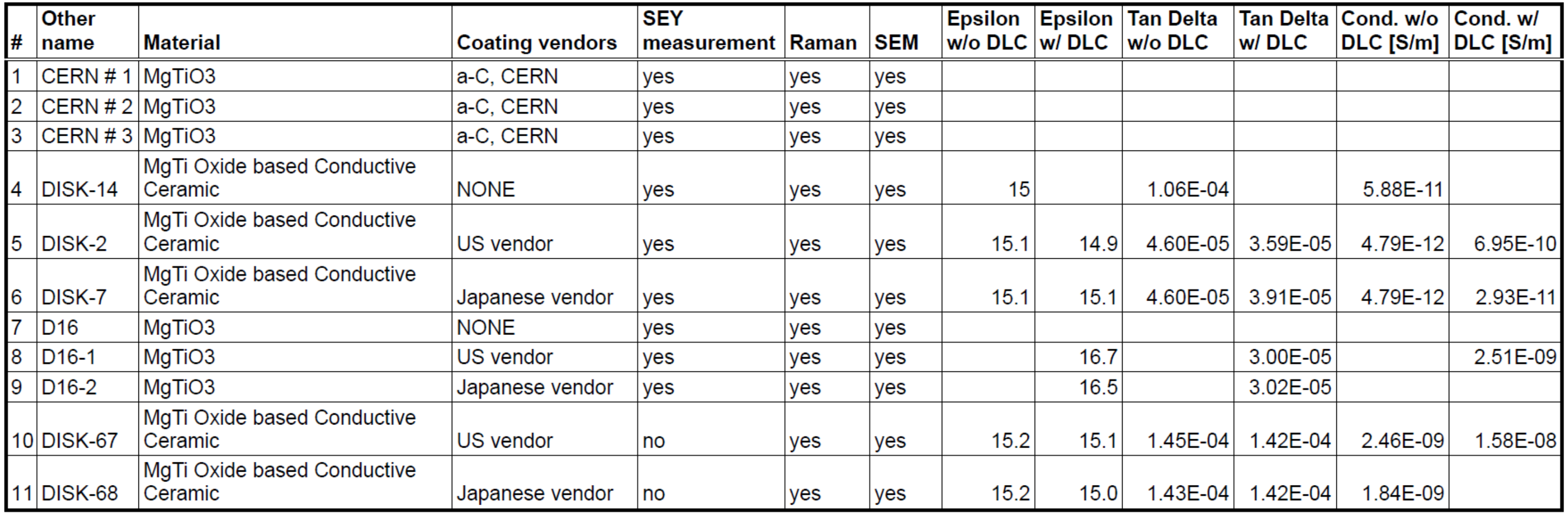
DISK 16_1



DISK 16_2



Investigating DLC coating at Euclid in Collaboration with CERN (III)

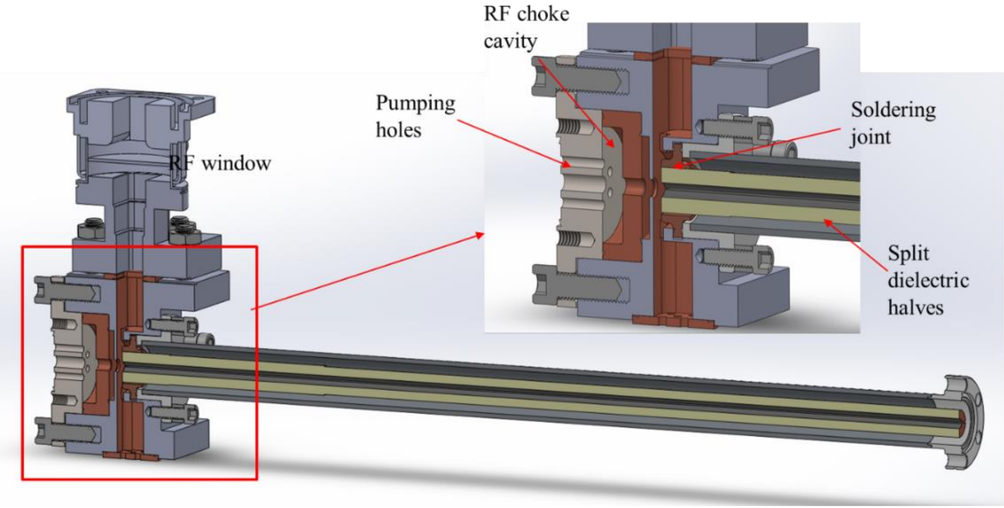


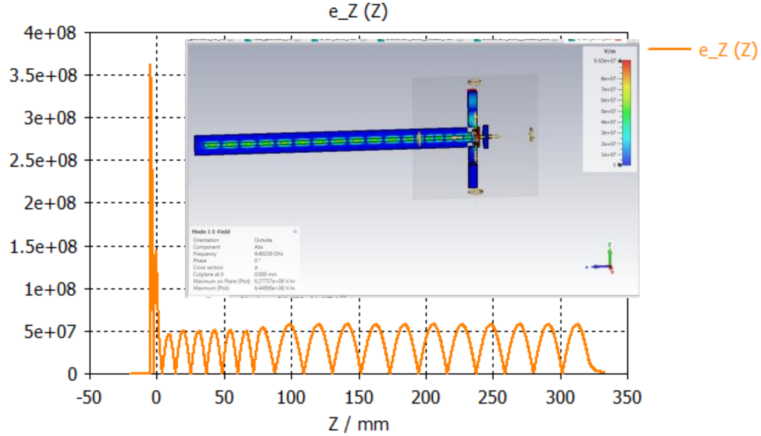
#	Other name	Material	Coating vendors	SEY measurement	Raman	SEM	Epsilon w/o DLC	Epsilon w/ DLC	Tan Delta w/o DLC	Tan Delta w/ DLC	Cond. w/o DLC [S/m]	Cond. w/ DLC [S/m]
1	CERN # 1	MgTiO3	a-C, CERN	yes	yes	yes						
2	CERN # 2	MgTiO3	a-C, CERN	yes	yes	yes						
3	CERN # 3	MgTiO3	a-C, CERN	yes	yes	yes						
4	DISK-14	MgTi Oxide based Conductive Ceramic	NONE	yes	yes	yes	15		1.06E-04		5.88E-11	
5	DISK-2	MgTi Oxide based Conductive Ceramic	US vendor	yes	yes	yes	15.1	14.9	4.60E-05	3.59E-05	4.79E-12	6.95E-10
6	DISK-7	MgTi Oxide based Conductive Ceramic	Japanese vendor	yes	yes	yes	15.1	15.1	4.60E-05	3.91E-05	4.79E-12	2.93E-11
7	D16	MgTiO3	NONE	yes	yes	yes						
8	D16-1	MgTiO3	US vendor	yes	yes	yes		16.7		3.00E-05		2.51E-09
9	D16-2	MgTiO3	Japanese vendor	yes	yes	yes		16.5		3.02E-05		
10	DISK-67	MgTi Oxide based Conductive Ceramic	US vendor	no	yes	yes	15.2	15.1	1.45E-04	1.42E-04	2.46E-09	1.58E-08
11	DISK-68	MgTi Oxide based Conductive Ceramic	Japanese vendor	no	yes	yes	15.2	15.0	1.43E-04	1.42E-04	1.84E-09	

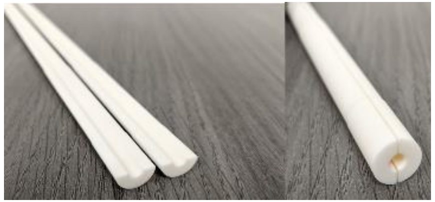
Details refer to: A. Grudiev, *et al*, *CLIC-Note-1175*, 2022

In Practice: A low energy split dielectric accelerator (I)--Development

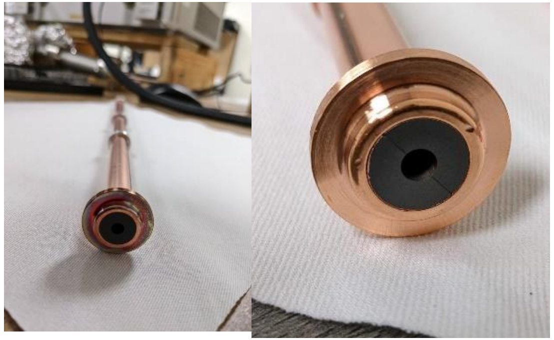
In order to apply DLC coating, the dielectric tube is cut into two halves.

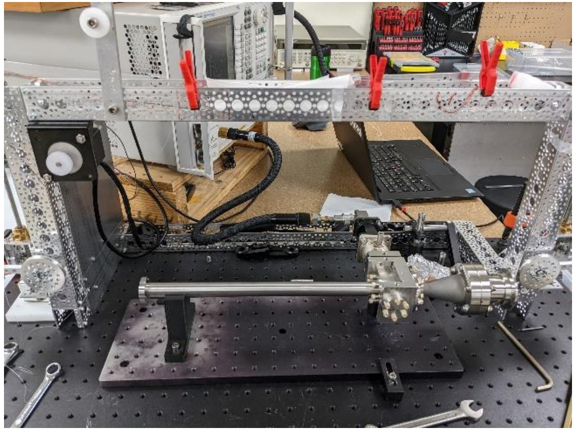






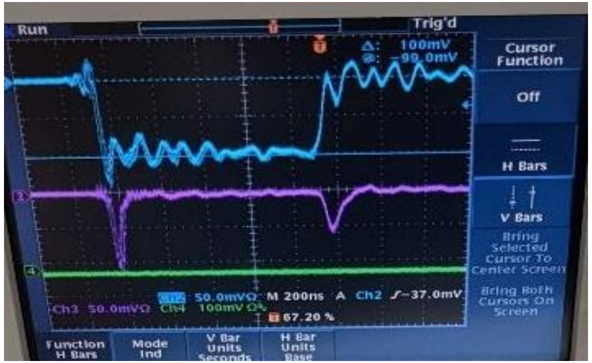
In Practice: A low energy split dielectric accelerator (II)--Test





3 typical MP traces

Conditioned away



- Multipactor can be fully suppressed in a few MV/m of gradient range.
- RF breakdown is still an issue to overcome.

Thanks NIH-NCI Contract 75N91021C00054

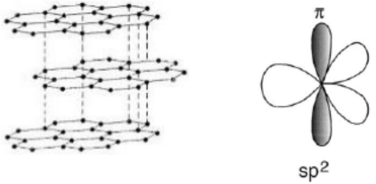
Summary and Next

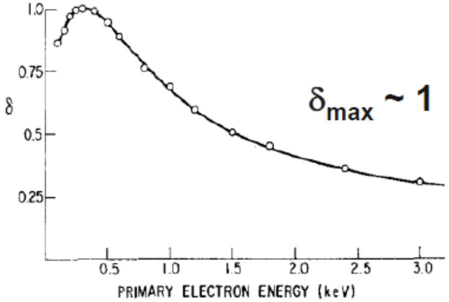
- Solving multipactor using the approach of Split DLA and DLC coating is promising. This may be an ultimate solution.
- RF breakdowns currently limits the final demonstration.
- If success, it will be a game changer for ultracompact linac for industrial applications

1 – Introduction to low SEE a-C films

The SEY (δ) of carbon materials depend on the molecular bonds between carbon atoms.

Graphite =>low SEY

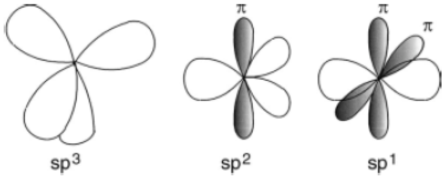


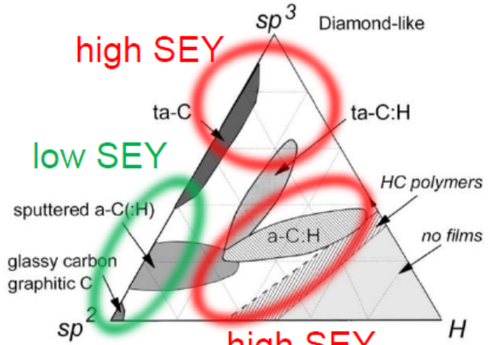


$\delta_{max} \sim 1$

N. REY WHETTEN JOURNAL OF APPLIED PHYSICS
VOLUME 34. NUMBER 4 (PART 1) APRIL 1963

Carbon thin films





high SEY

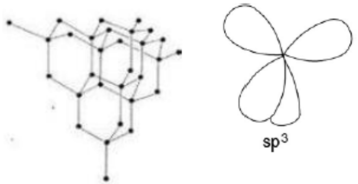
low SEY

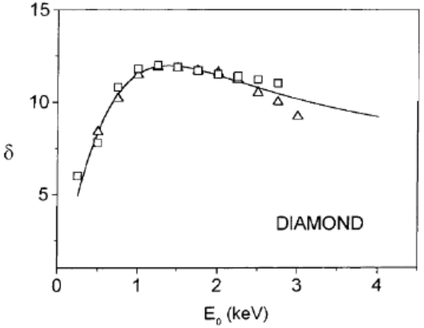
high SEY

Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

J. Robertson / Materials Science and Engineering R 37 (2002) 129–281

Diamond => high SEY





JACQUES CAZAUX, Mikrochim
. Acta 132, 173±177 (2000)