Dielectric Accelerators in Cryogenic Temperature

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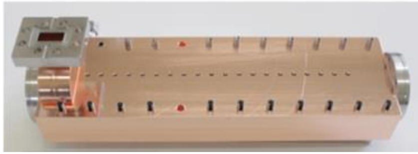
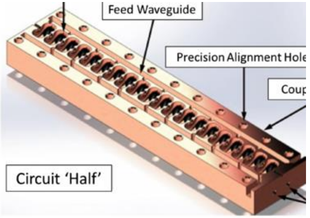
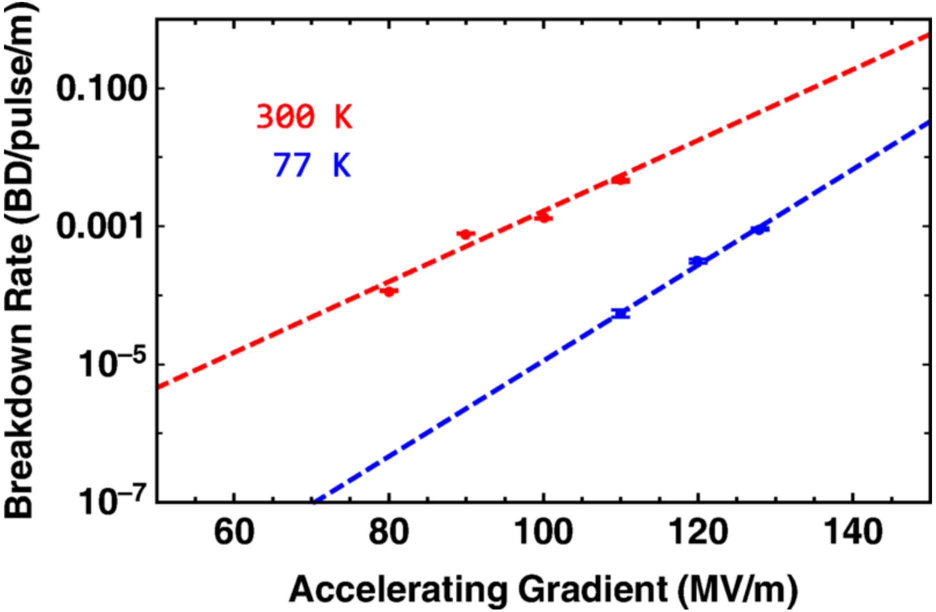
Motivation (I)---Cold Copper Structure



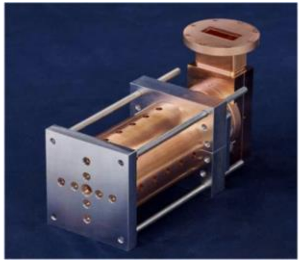


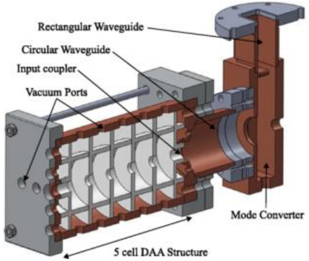
- Sami Tantawi, *et al, Phys. Rev. Accel. Beams* **23**, 092001 (2020)
- Mamdouh Nasr, *et al, Phys. Rev. Accel. Beams* 24, 093201 (2021)

Parameter	300 K	77 K
Frequency (GHz)	11.402	11.438
Q_0	10000	22500
Q_{ext}	10000	10000
Shunt impedance $(\mathrm{M\Omega/m})$	155	349
Peak surface E (MV/m)	250	250
Peak surface H (MA/m)	0.575	0.575
Steady state rf power (MW)	17	9
Iris diameter (mm)	2.6	2.6
Length (cm)	26	26

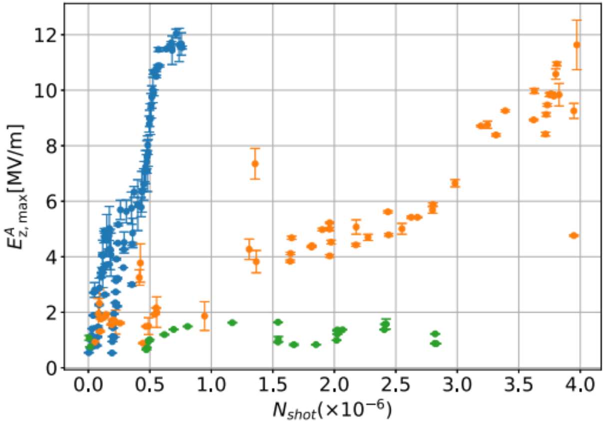


Motivation (II)---Dielectric Assisted structure in cold





- Daisuke Satoh, et al, Phys. Rev. Accel. Beams 20, 091302 (2017)
- Daisuke Satoh, *et al, Nucl. Inst. and Meth. Phys. Res. B 459 (2019) 148–152*.
- Shingo Mori, et al, Phys. Rev. Accel. Beams 24, 022001 (2021)

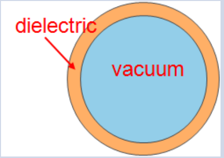
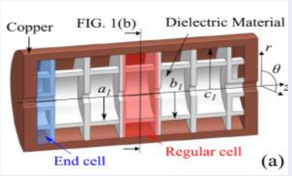
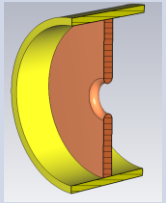
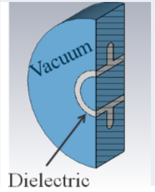


Parameter	Five-cell DAA structure
Dielectric material	Magnesia
ϵ_r	9.64
$\tan\delta$	6.0×10^{-6}
Accelerator type	Standing wave type
Accelerating mode	TM_{02}-π mode
Operation frequency	5.712 GHz
Number of accelerating cells	5
Total cavity length	157.5 mm
Q_0	126,400
Z_{sh}	630 MΩ/m
E_{max}/E_0	2.92
H_{max}/E_0	2.74 mA/V

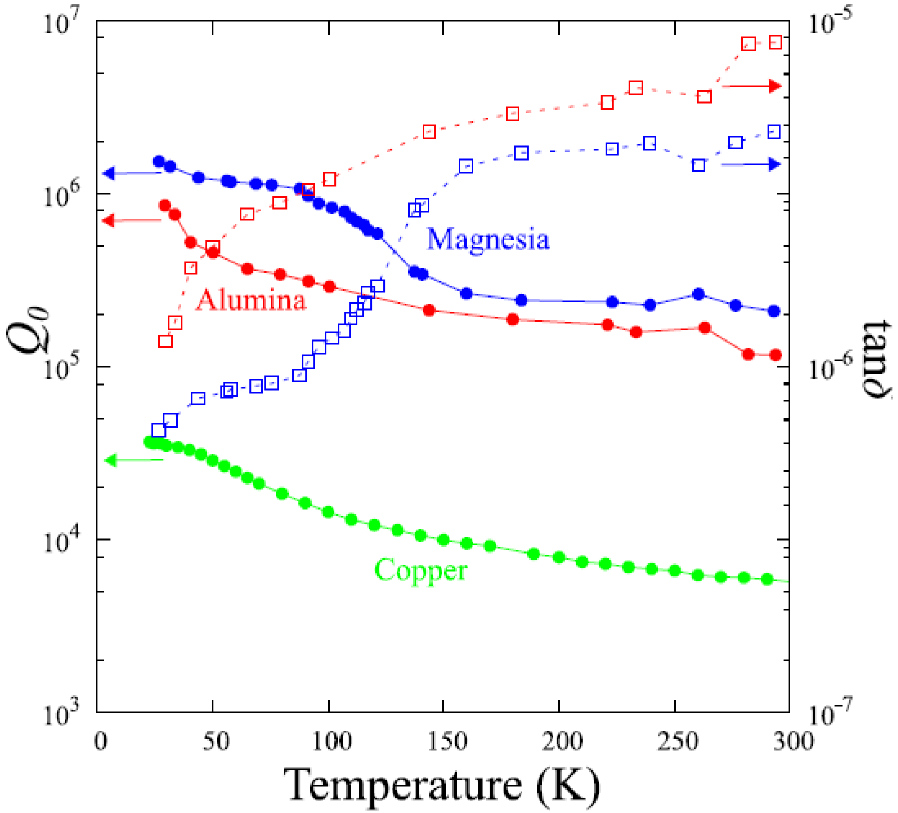
Basic cavity and accelerator parameters of cryogenic temperature operating DAA structure.

Parameters	MGO5CV1
Acc. type	standing wave type
Acc. Mode	TM_{02} - π mode
Number of Acc. cells	5
Frequency	5.712 GHz
Temperature	27 K
Dielectric Material	Magnesia
ε_r	9.64
tanδ	6.6×10^{-7}
Q_o	765,300
Z_{sh}	3.8 GΩ/m

Motivation (III)--- comparison

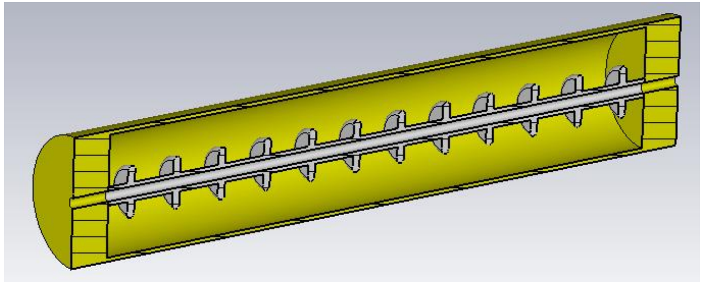
Variety of dielectric structures	Pros	Cons
 Dielectric loaded accelerator	- Most developed structure - Simple fabrication - Low surface fields	- Moderate r/Q ~20MΩ/m - Weak points: tapered matching section
 Dielectric assisted accelerator	- Very high shunt impedance ~620MΩ/m - Prototype fabricated	- Operated in TM_{02} mode; vulnerable to TM_{01} mode excitation. - Very complicated in fabrication; Current prototype is clamped together, and may not sustain high gradient - Weak points: high surface fields at joint between copper and dielectric
 Dielectric disk accelerator	- High shunt impedance ~120MΩ/m - TM_{01} mode operation - Easy tuning of each cell possible - Operation in different modes same as conventional copper structures (TW w different phase advance, SW) - Cryogenic shunt impedance ~550MΩ/m	- Many pcs needed - Connection to copper is challenging
 Dielectric corrugated accelerator	- Moderate shunt impedance ~80MΩ/m - Feasibility of single piece fabrication - TM_{01} mode operation - Cryogenic shunt impedance ~550MΩ/m	- Mechanical support and cooling are only at the ends - Necessary for support and cooling end walls reduce shunt impedance - Not many parameters to improve shunt impedance

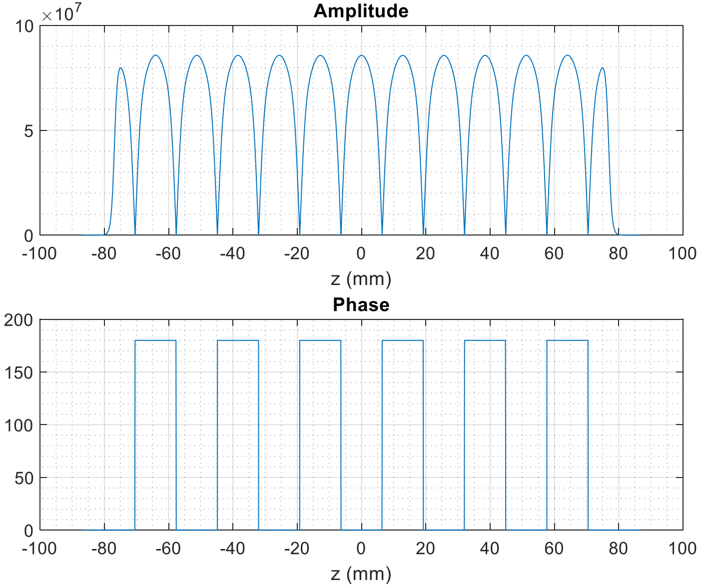
Dielectric Materials in Cold

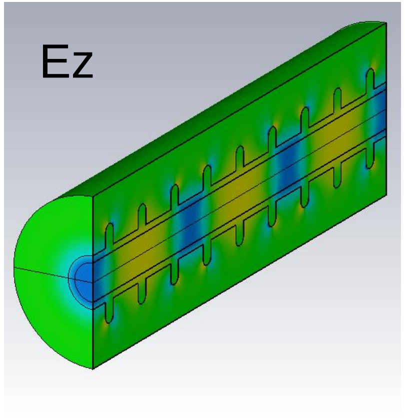


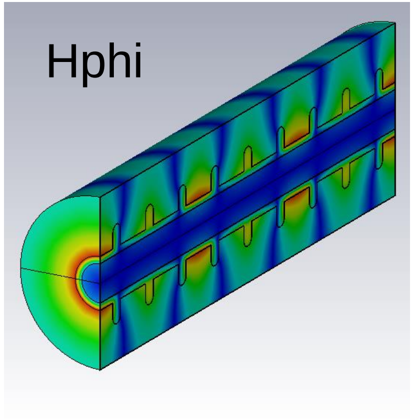
Ref.: Daisuke Satoh, *et al, Nucl. Inst. and Meth. Phys. Res. B 459 (2019) 148–152*.

Example 1: Cryogenic Dielectric Corrugated Accelerator (I)







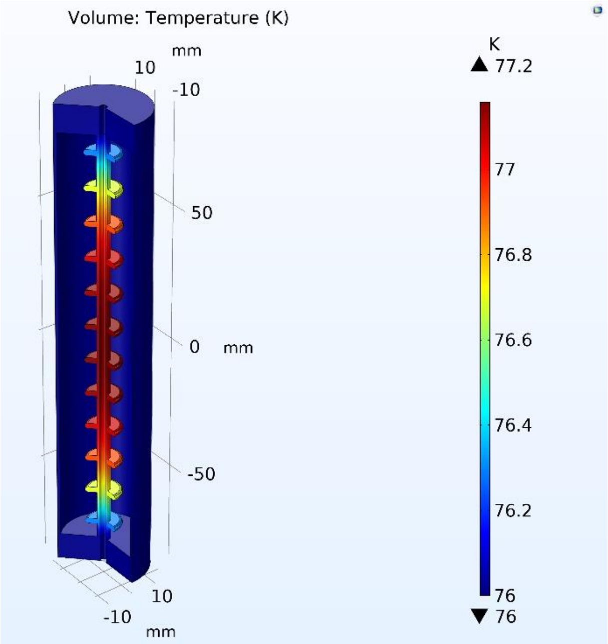


Example 1: Cryogenic Dielectric Corrugated Accelerator (II)

	tan(δ)	σ_{copper} (S/m)	Q	r/Q (kΩ/m)	r (MΩ/m)
77 K	3e-6	3.0e8	1.11e5	4.91	547.41
300 K	1e-4	5.8e7	1.75e4	4.91	86.06

Note: Other major simulation parameters: f=11.7 GHz, beam aperture 2a=2.6 mm, TM_{01} π-mode standing wave, dielectric constant=9.8.

The thermal simulation of the X-band DCA prototype under 100 MV/m of gradient and 28 W of heat load (low duty factor at AWA).



thermal conductivity of alumina @ 77 K = 100 W/(m*K)

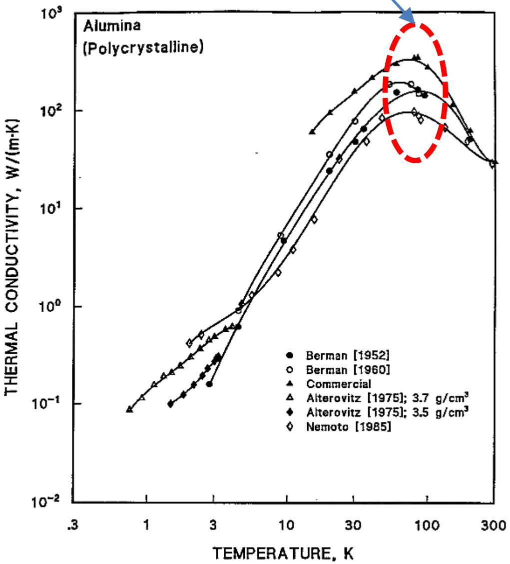
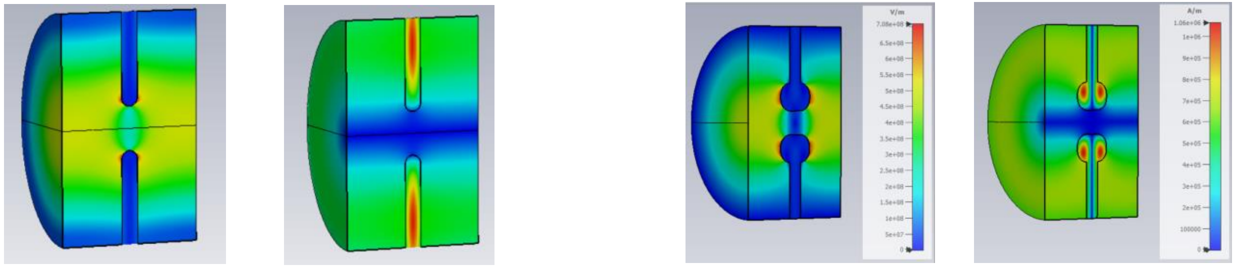


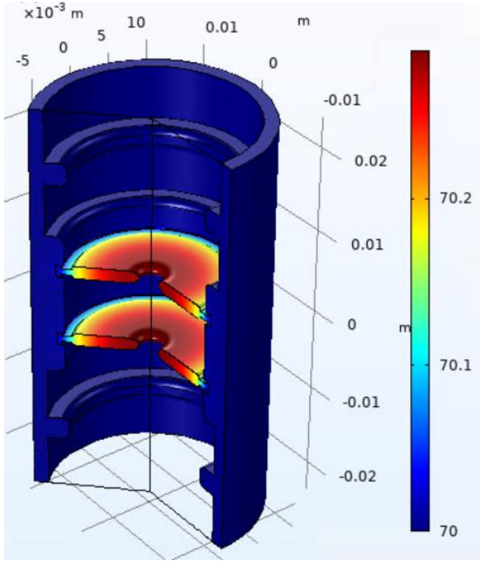
Figure 2.4.2. Thermal conductivity of polycrystalline Al_2O_3 vs. temperature. Data from Berman [1952], Berman et al. [1960], Alterovitz et al. [1975], Nemoto et al. [1985], and Touloukian et al. [1970; citations therein].

Example 2: Cryogenic Dielectric Disk Accelerator



Structure	Temp, K	aperture	epsilon	Rsh, MΩ/m
DDA	300	4	50	165
DDA	300	2.6	50	181
DDA	77	4	50	423
DDA	77	2.6	50	463
DDA 2mm nose, Epk=2.5 (same as SLAC)	77	2.6	50	550
DDA 3mm nose, Epk=5	77	2.6	50	706

Note: Room temperature copper conductivity 5.8E7 S/m, cryogenic conductivity is 3E7 S/m; Dielectric loss at room temperature is 1E-4, at cryogenic temperatures is 3E-6.



The thermal simulation of the X-band DCA prototype under 100 MV/m of gradient and 28 W of heat load.

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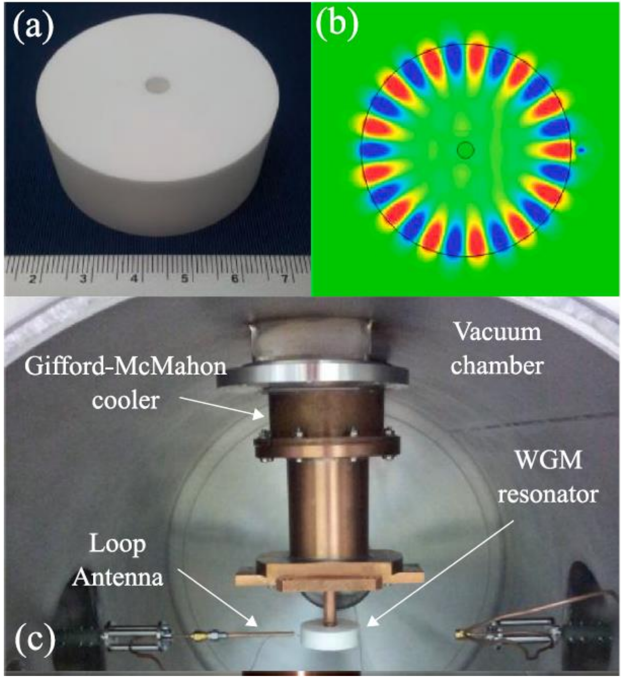
Summary and Next

- Dielectric accelerator in Cryogenic temperature shows surprisingly high shunt impedance.
- Challenges remains as conventional dielectric accelerators, i.e. breakdowns due to variety of micro gaps.
- Worth to explore. The first step is to characterize different dielectric materials at low temperature.



Ref.: Daisuke Satoh, *et al, Nucl. Inst. and Meth. Phys. Res. B 459 (2019) 148–152*.