Absorptive Infrared Blocking Filters

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CMBPOL Technology workshop
Aug 26, 2008

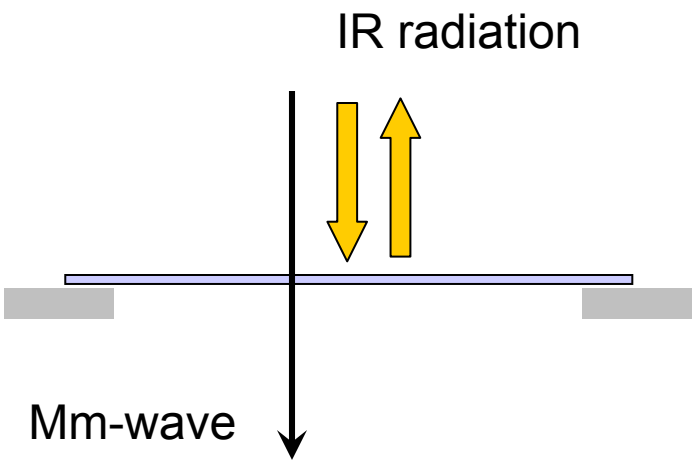
The purpose of IR filtering

- **Primary: Reducing the thermal radiation onto the 4K and/or VCS stages**
- Reducing the loading on the sub-K stages (on the sub-K absorptive filters)

- *It is not the IR blockers' job to cut off high frequency leaks!*

Metal-mesh versus Dielectric

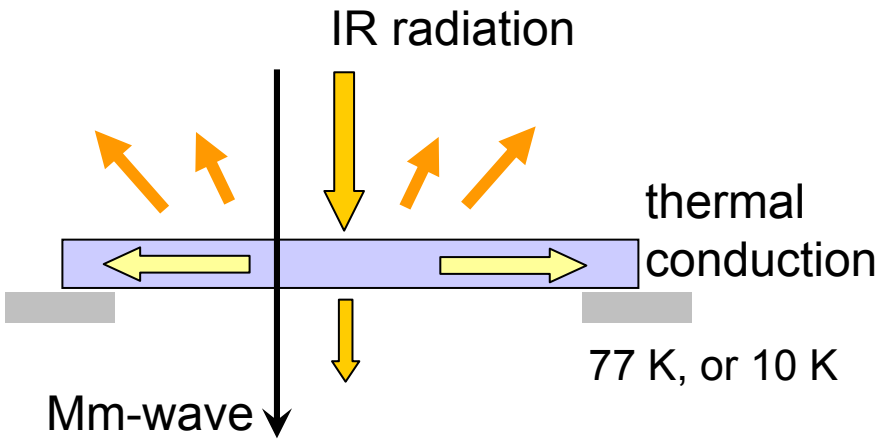
(reflective)



An ***Ideal*** reflective IR blocker:

* 100% transmission in band
* 100% reflection out of band

(absorptive)



An ***Ideal*** absorptive IR blocker:

* 100% transmission in band
* 100% absorption out-of-band
* Good thermal conductivity

The material requirements

- Efficient IR blocking
- High thermal conductivity (filter temperature↓)
- Good In-band transmission (loading↓and signal↑)
- Low index of refraction, and/or AR coating

Some low loss dielectric materials

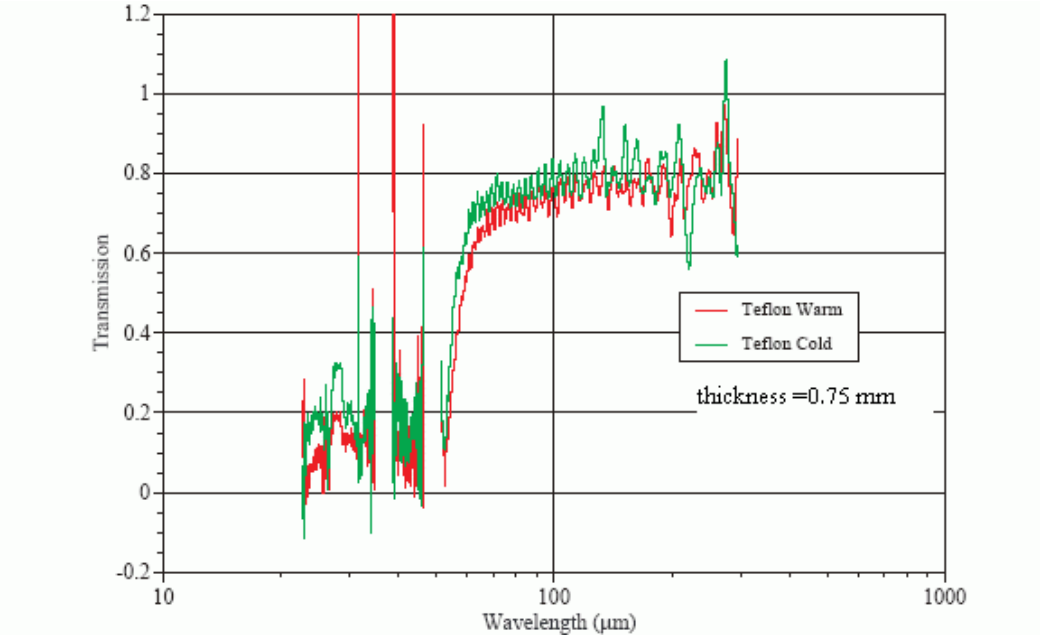
Material properties	Index of refraction	Absorption at 150GHz Nepers cm^{-1}	Reflective loss per interface	Absorption at 3000GHz Nepers cm^{-1}	Thermal conductivity mW cm^{-1} K^{-1}
Expanded PTFE (ZITEX, Mupor)	1.2	small	0.83%	~100 for thin sheets	
PTFE (Teflon)	1.44	0.015	3.3%	3.0	2.2 (80 K) 1.4 (20 K)
Glass-filled PTFE (Fluorogold)	1.65	0.16	6.0%	>30	
Fused quartz	1.9	0.05-0.07	9.6%	large	5.3 (80 K) 1.4 (20 K)

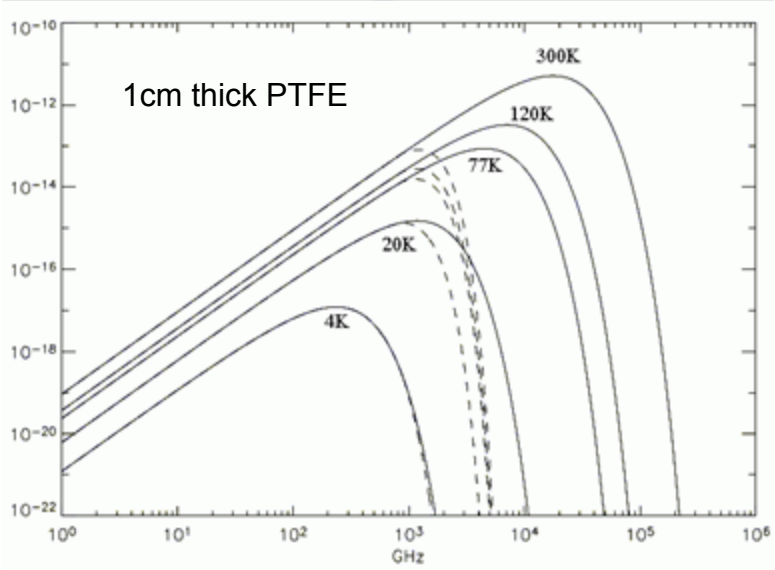
The key figure of merit is α_{IR}/α_{mm}

PTFE seems to be a good candidate

- Expanded PTFE:
  *low thermal conductivity
  *inefficient in bulk
- Glass-filled PTFE:
  *high refractive index
  *high mm-wave loss, and polarized
- Fused quartz:
  *high refractive index
  (and hard to AR-coat due to unmatched thermal expansion)

IR properties of PTFE



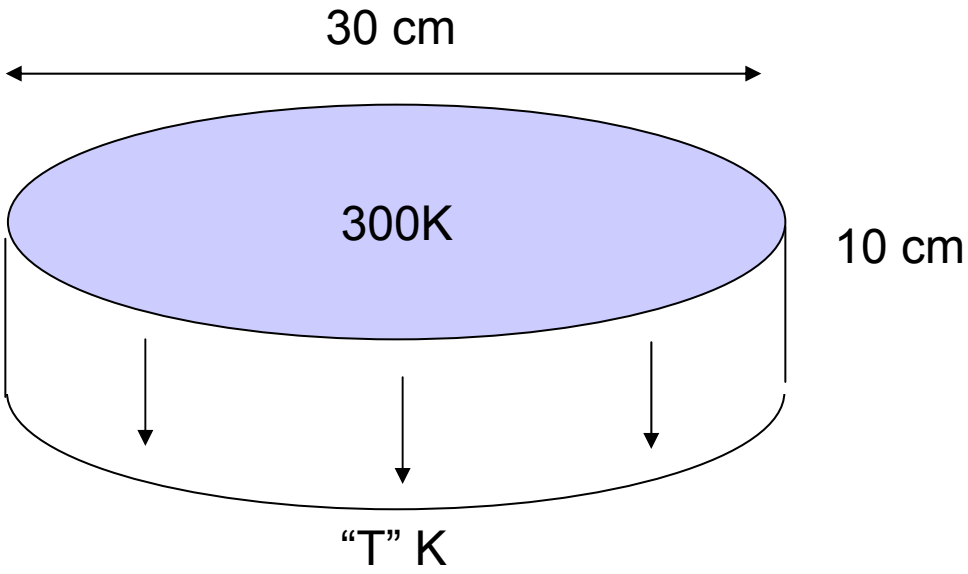


Source Temp (K)	Transmittance %	Transmitted (mW)
300	0.072	23
120	0.95	7.9
77	3.1	4.3
20	47.8	0.3
4	99.9	0.001

Benford et al.

4K PTFE filter is inefficient

Order of Magnitude calculation: Zotefoam PPA30



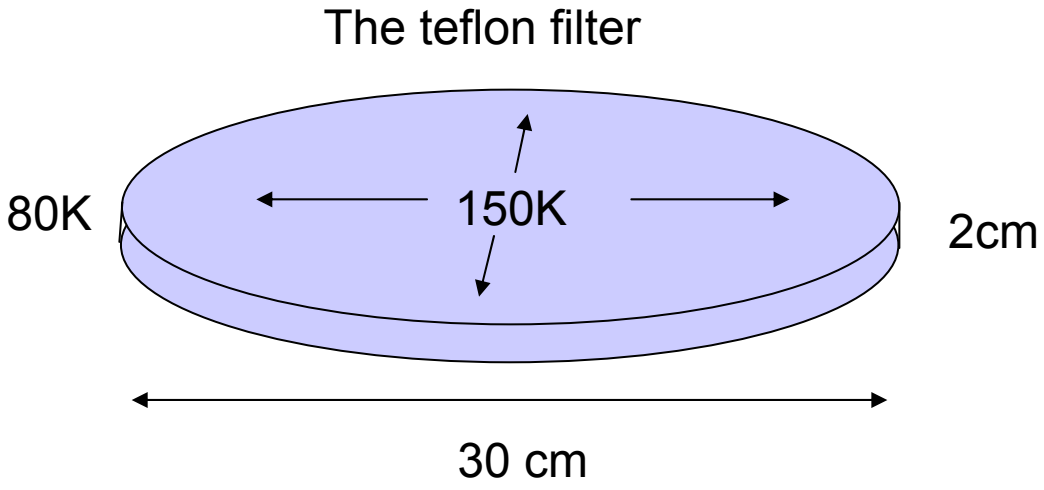
$\kappa(300K)$=4e3 erg/s/cm/K

κ ((300-T)/10) x ($\pi 15^2$) = σ T^4 x ($\pi 15^2$)

κ~ 2000 erg/s/cm/K σ= 5.67E-5 erg/s/cm^2

T~ 150 K **(measurement: ~190 K)**
Power ~ 2 Watts **(measurement: 7.5W)**

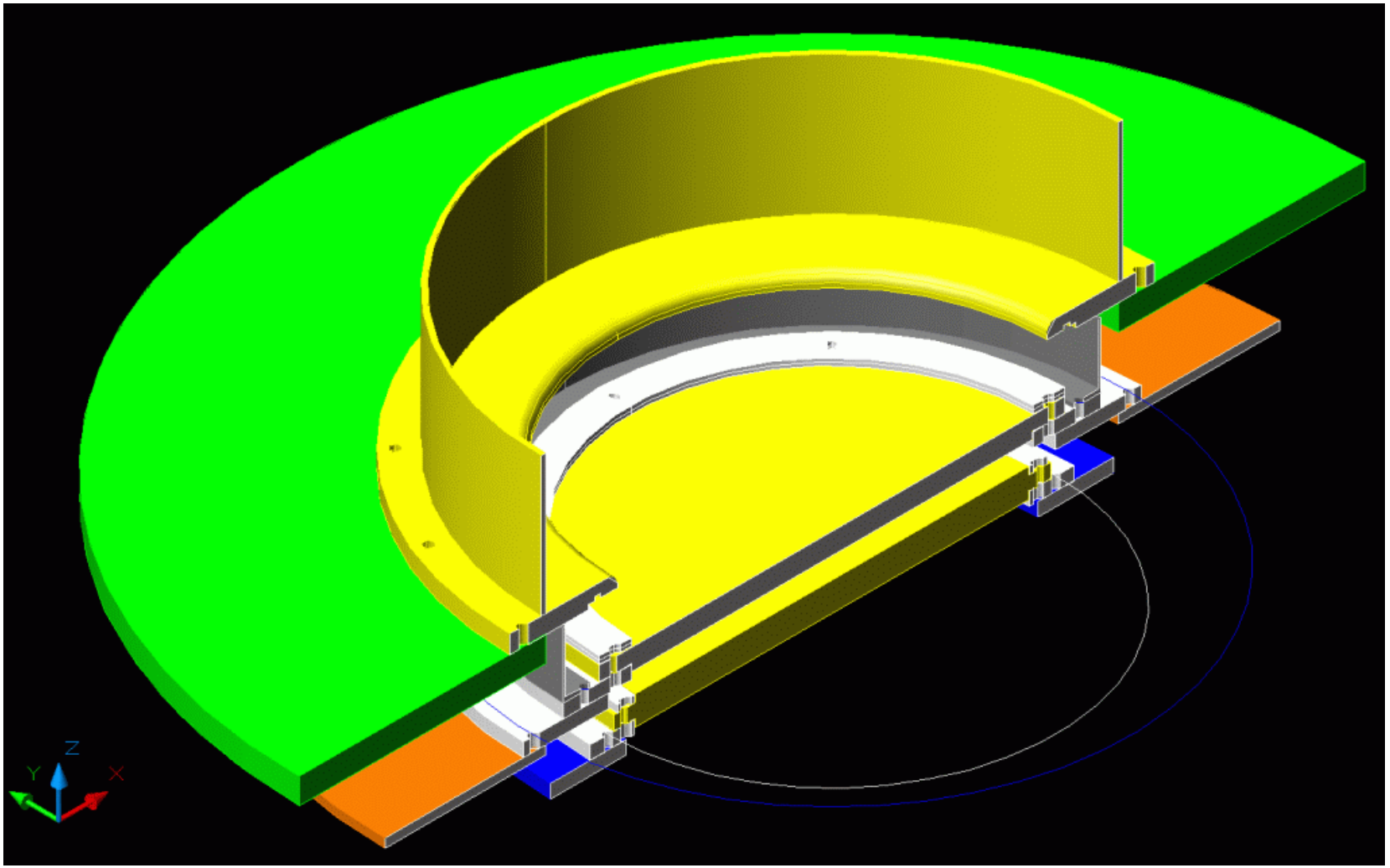
Order of Magnitude calculation: Teflon(PTFE)



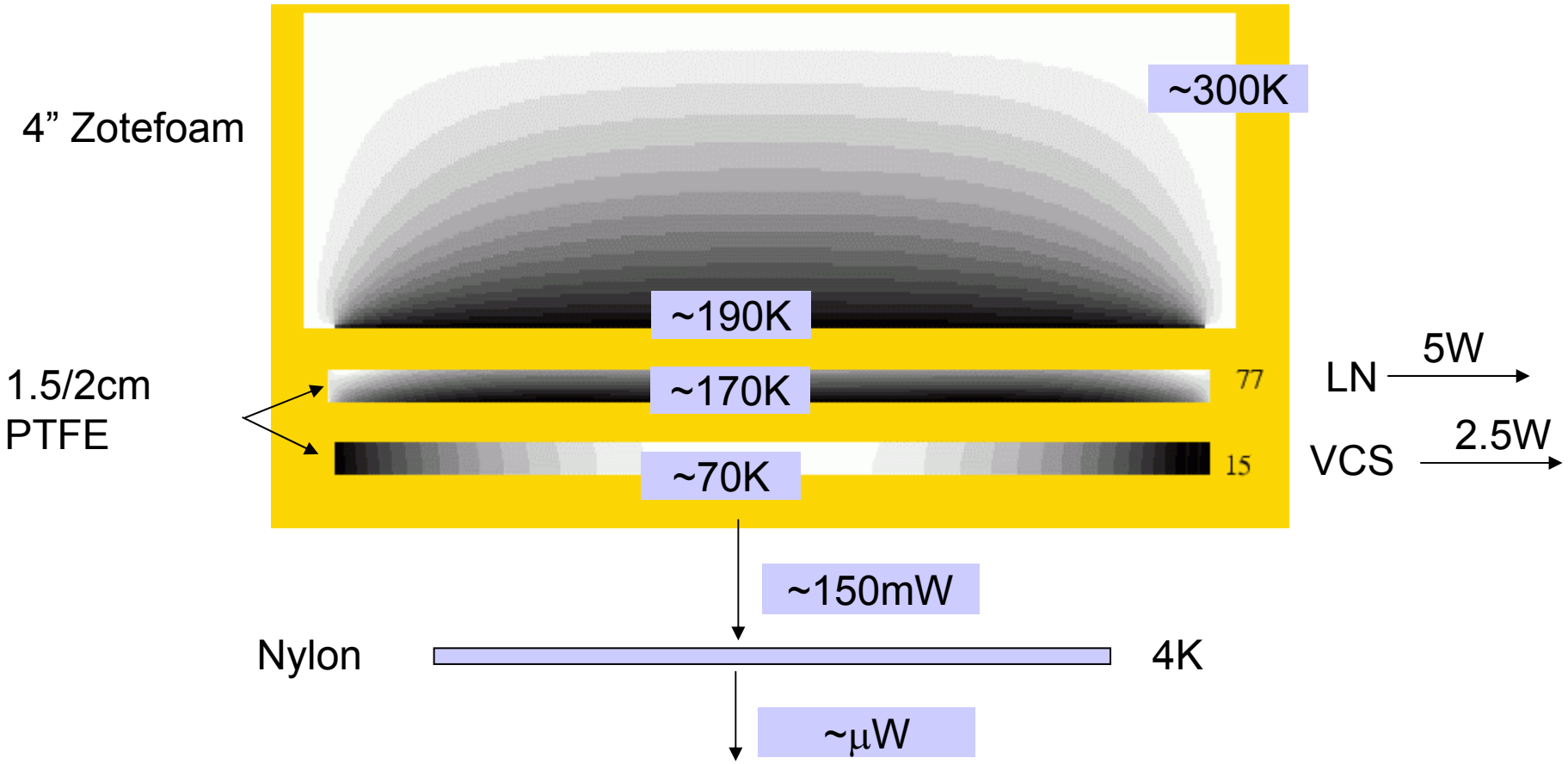
(π30) x ((150-80) / 15) x 2.2 (mW K^{-1} cm^{-1})*2 cm ~ 2 Watts **(measured=5W)**

Heat sinking

- Teflon shrinks 1.9% from 300K→20K



BICEP/BICEP-2 thermal filtering



Comparison with metal mesh filters (for CMBPOL)

- Cheap, easy to fabricate, arbitrarily large aperture
- Works at extreme oblique angles
- Well understood polarization properties
- Easy to AR coat

- ***Deciding factor: which type has the lower mm-wave (in-band) loading***