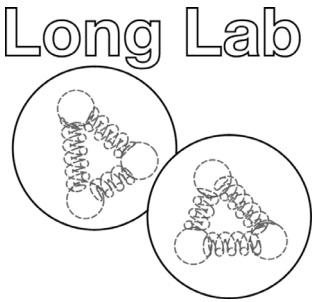
3D-Printed Millimeter-Wave Lenses for DNP Target System

KELLIE MCGUIRE

SENIOR RESEARCH PRESENTATION

MAY 6, 2019



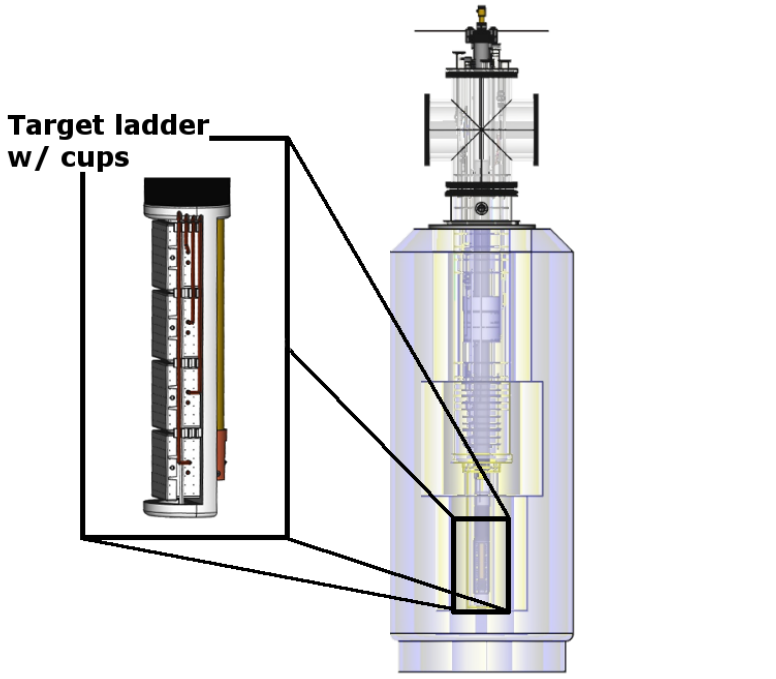
Dynamic nuclear polarization (DNP)

- **Prepare a nucleon target with unpaired electrons**
- **Place target in a strong magnetic field (e.g., 5T)**
- **Cool to cryogenic temperatures (~1K); ~99.8% of unpaired electrons are polarized**
- **Irradiate with microwaves to induce electron-to-nucleon spin transfer (the solid effect)**

$$h\nu = B(g_e\mu_e + g_p\mu_p)$$

For 5 T magnet, ν = 140 GHz (λ ≈ 2.14 mm → millimeter waves)

DNP target system



DNP system
(Image courtesy of UNH Nuclear Physics Group)

Need suitable material for the target cups:

1. **Transparent to mm-waves**
2. **Good cryogenic properties**
3. **No proton NMR signal**

Kel-F (PCTFE) has all of these properties.

3D-printing with Kel-F

Why 3D-printing?

- **Rapid prototyping**
- **Complex geometries**
- **Minimal waste**

3D-printing with Kel-F

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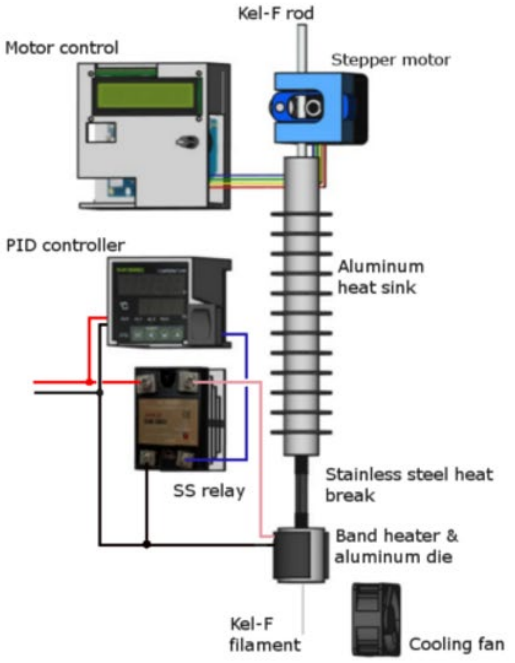
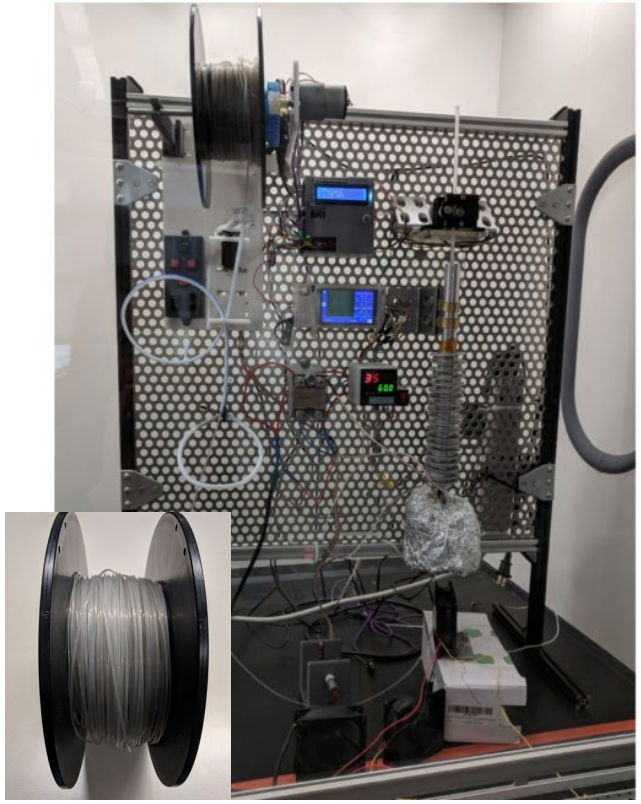




“Filatizer” for making Kel-F printer filament.

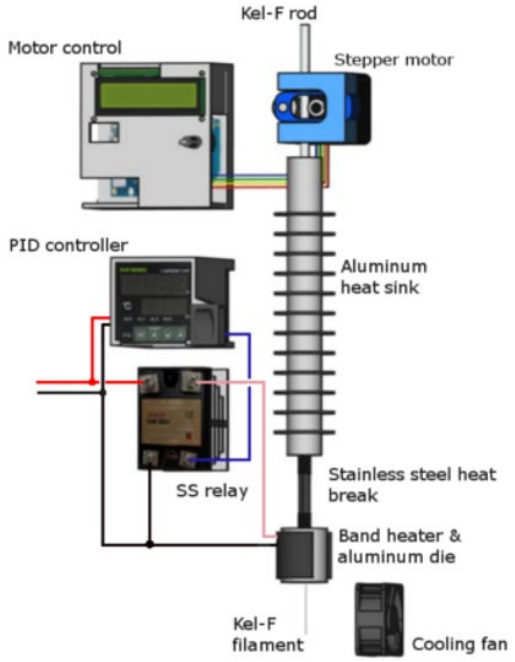
3D-printing with Kel-F

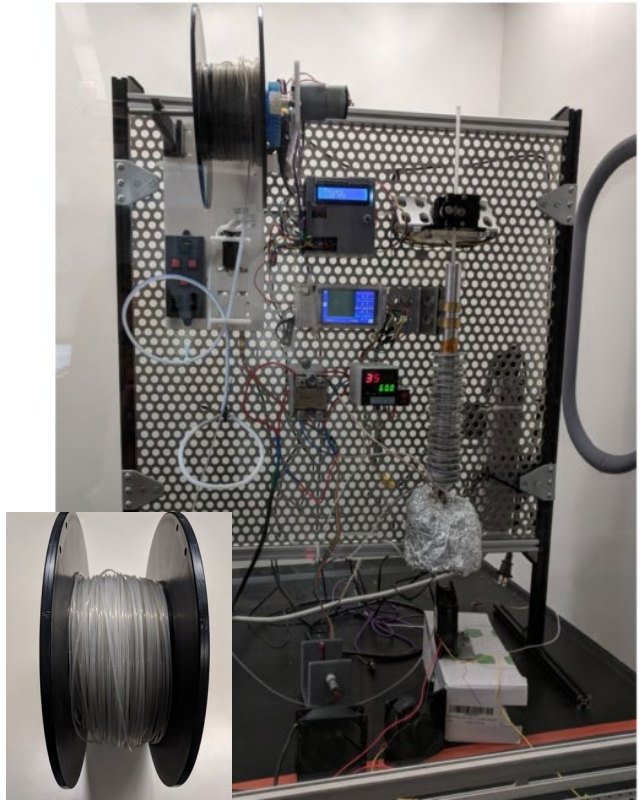
Why 3D-printing?

- Rapid prototyping
- Complex geometries
- Minimal waste

Kel-F challenges:

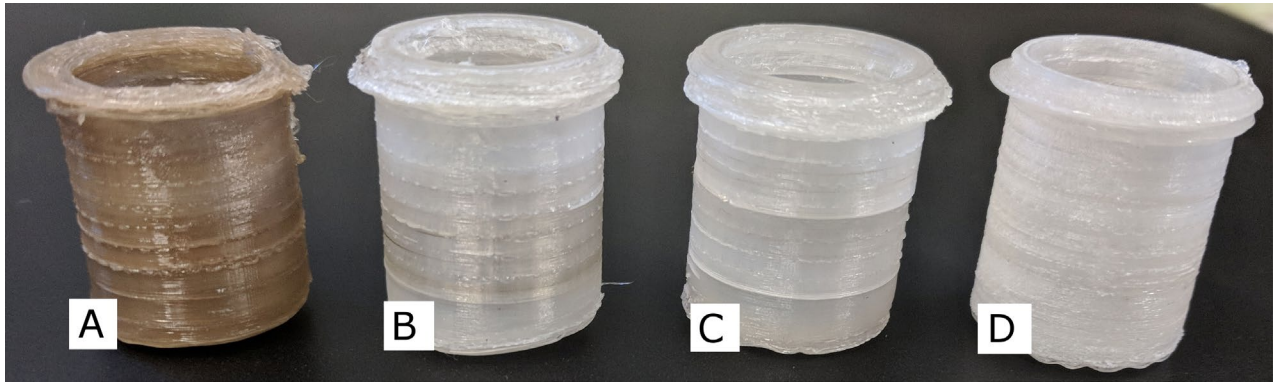
- Thermally unstable
- Highly viscous
- Self-lubricating
- HCl and HF decomposition





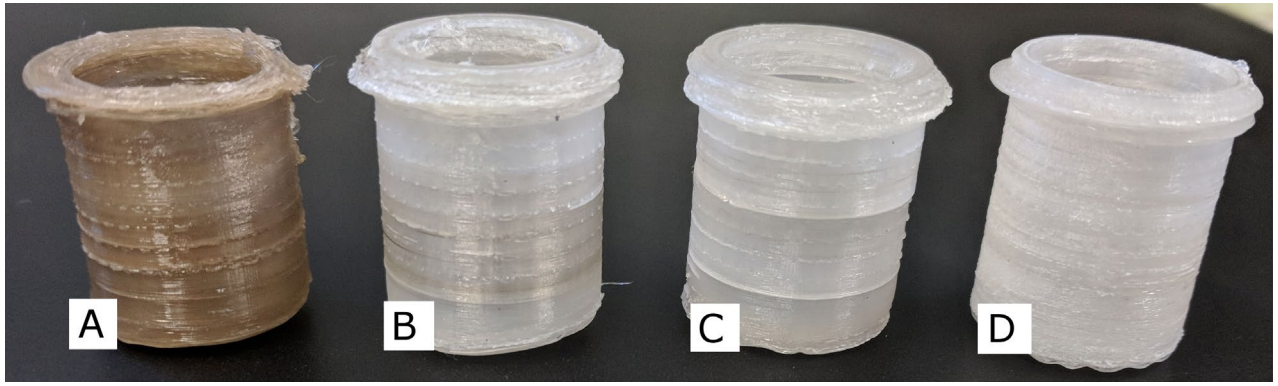
“Filatizer” for making Kel-F printer filament.

Kel-F target cups



Quality of print can vary dramatically and is highly dependent on temperature and speed of extrusion.

Kel-F target cups



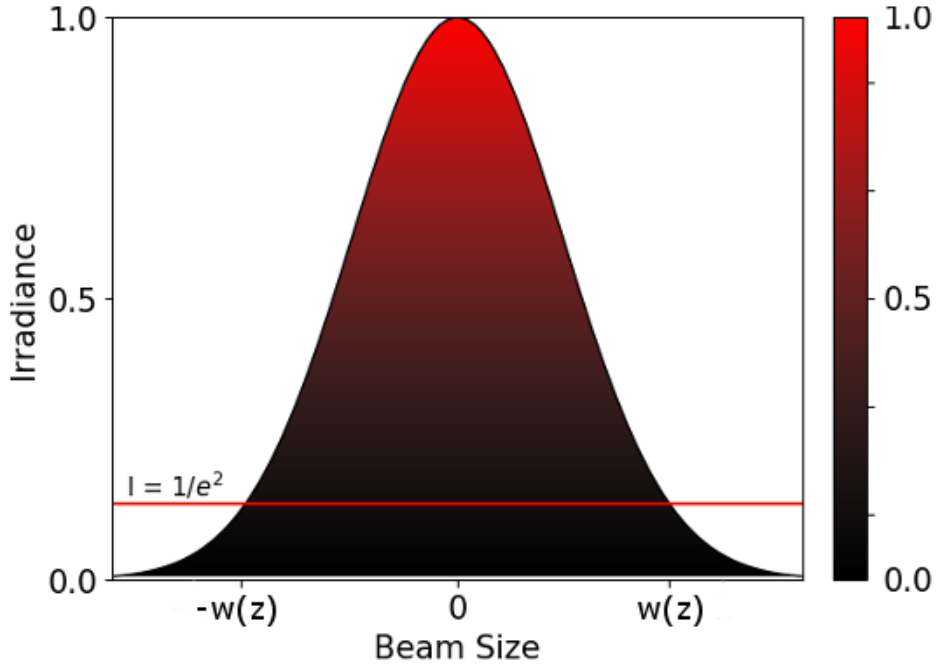
Quality of print can vary dramatically and is highly dependent on temperature and speed of extrusion.

3D-printed Kel-F target cups survived cooling to 1K.

Kel-F lenses

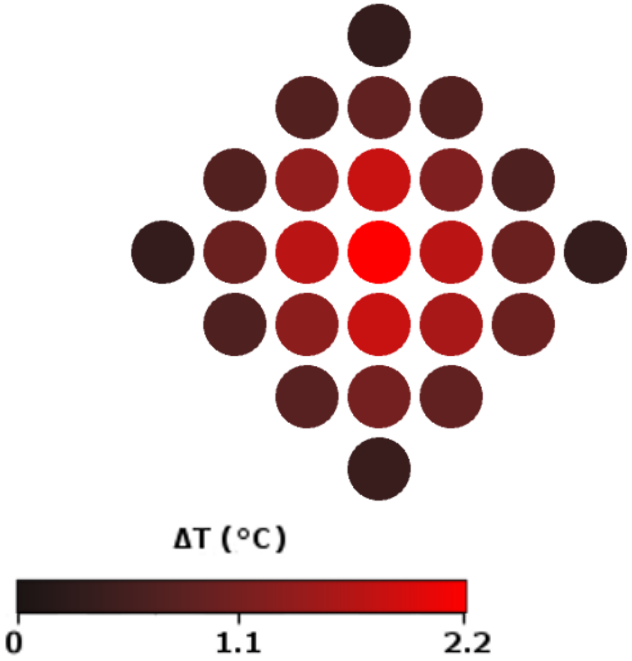
The polarizing radiation is in the form of a Gaussian beam incident on the target.

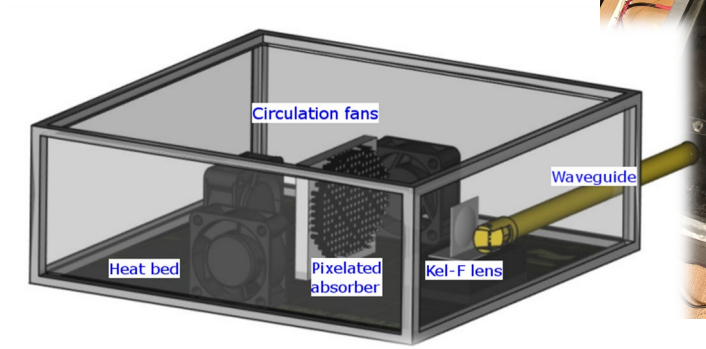
3D-printed lenses could be built into the target cups to evenly distribute the beam and help drive up the degree of nucleon spin polarization.

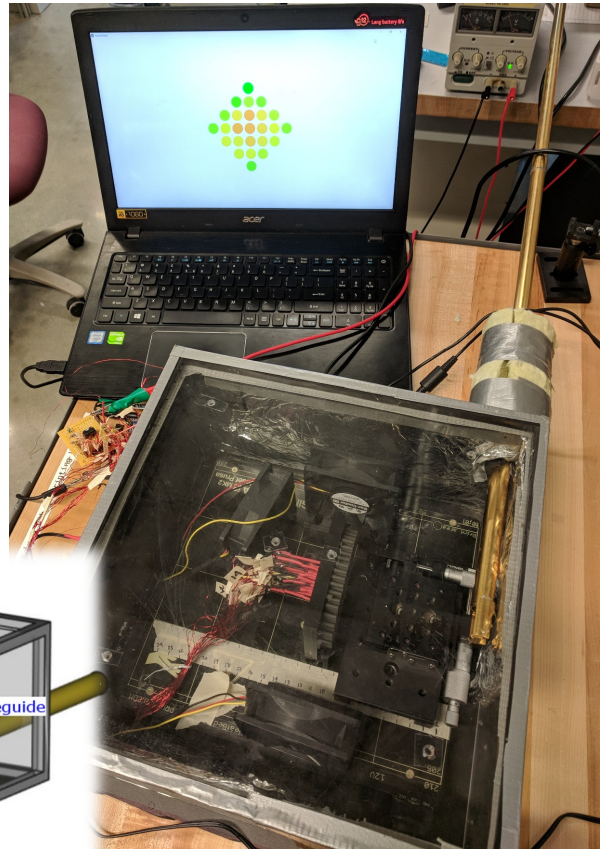


Kel-F lenses

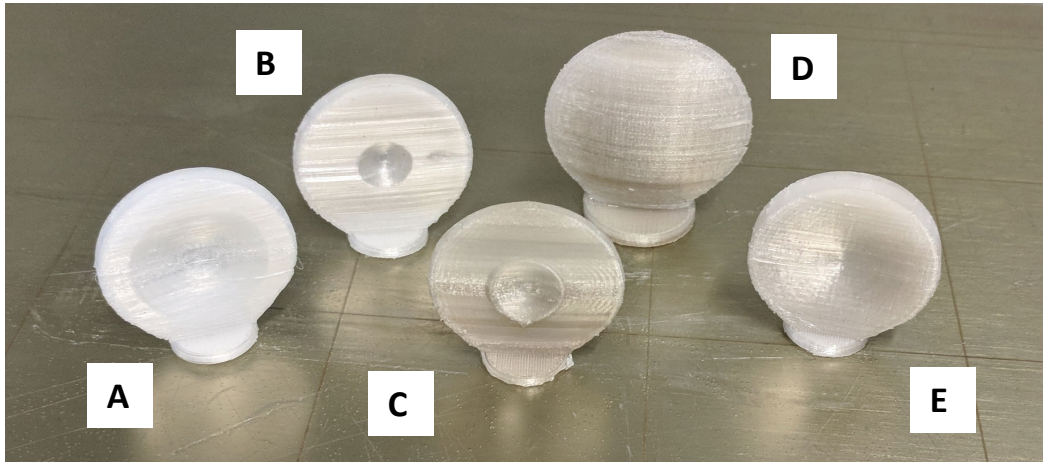
Beam is imaged using a calorimeter consisting of 25 “pixels” 3D-printed with iron-infused PLA and positioned inside a temperature-controlled box.



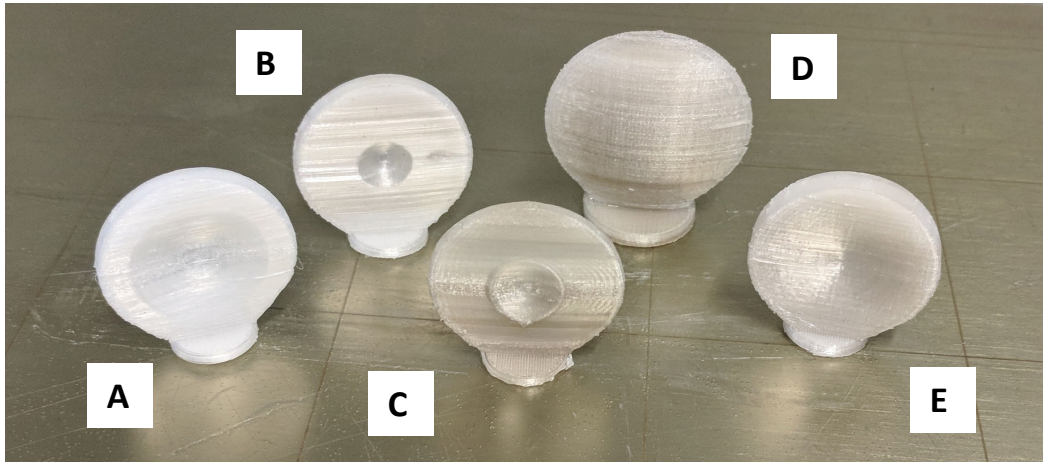


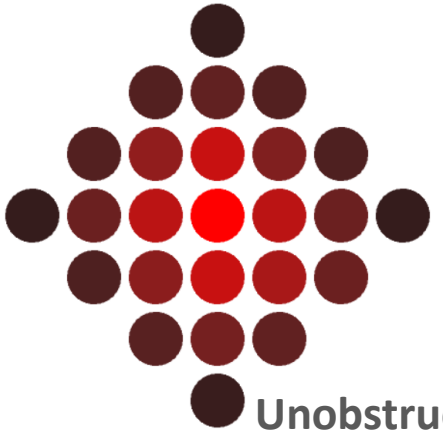


Kel-F lenses

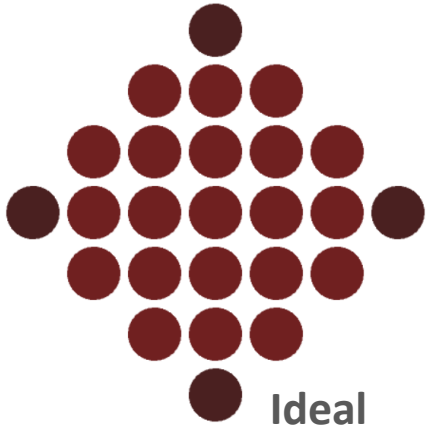


Kel-F lenses



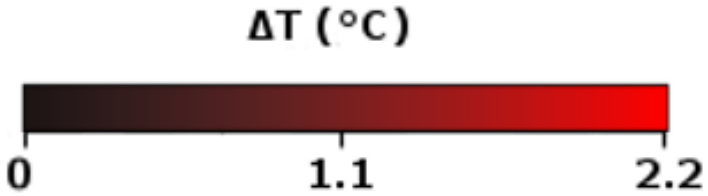


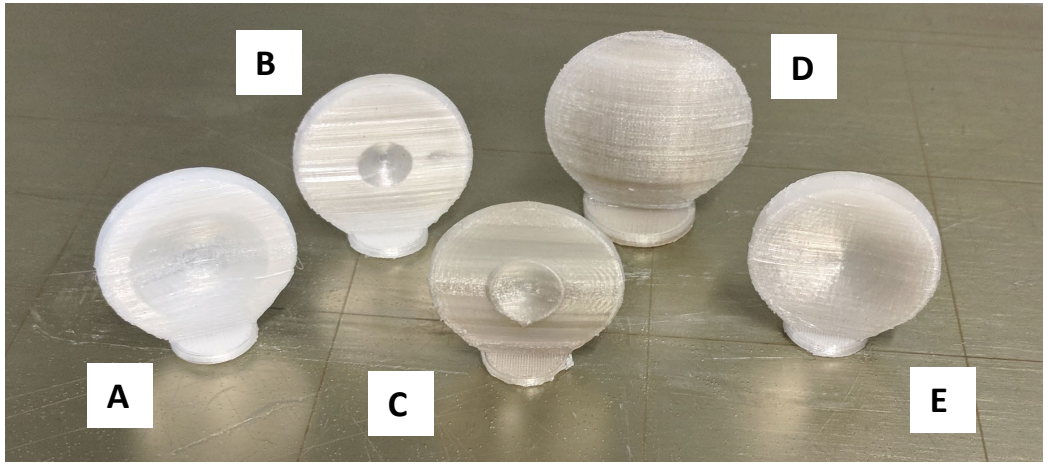
Unobstructed

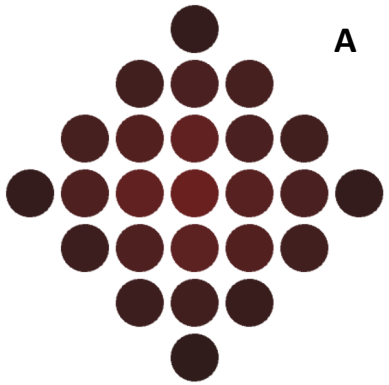


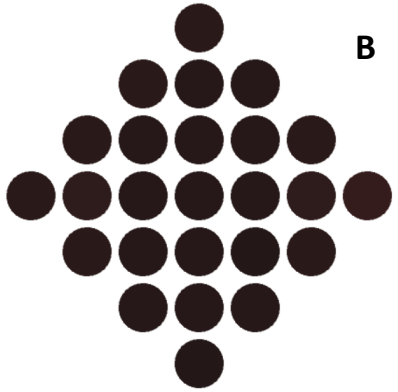
Ideal

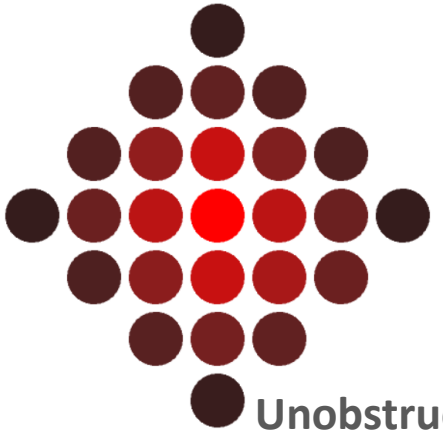
Kel-F lenses

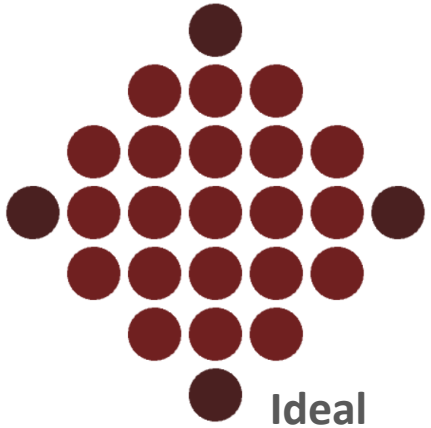


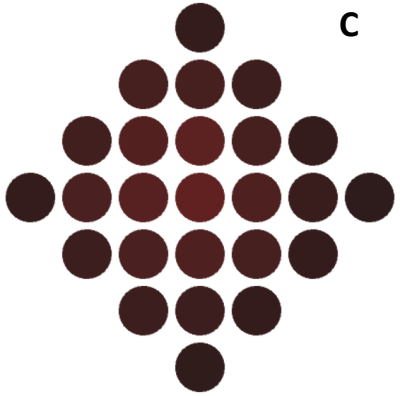


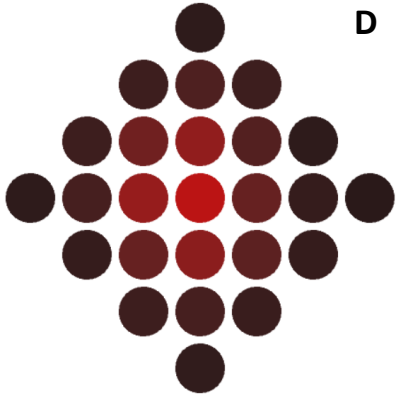




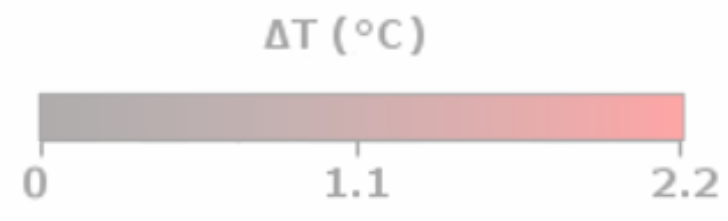


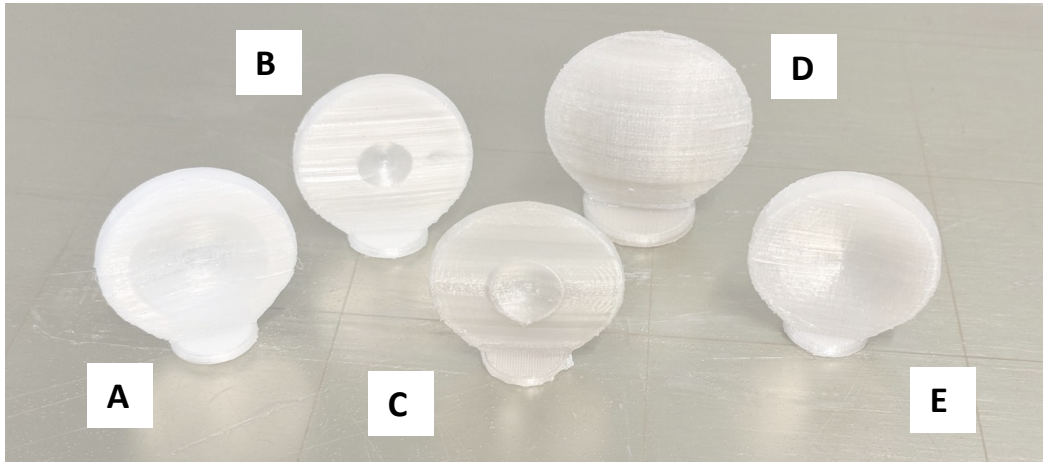


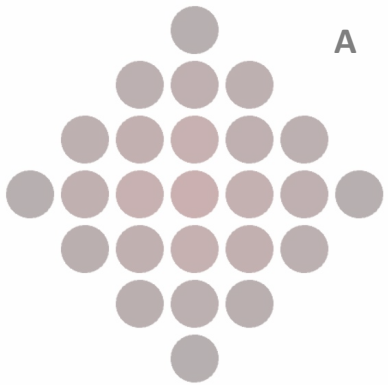


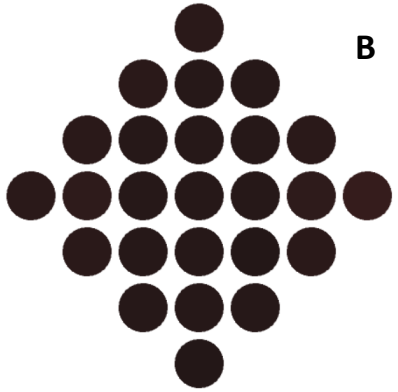


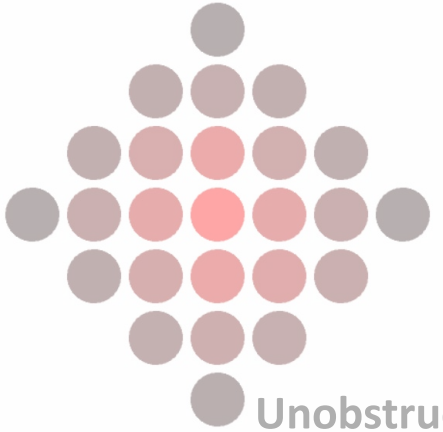
Kel-F lenses

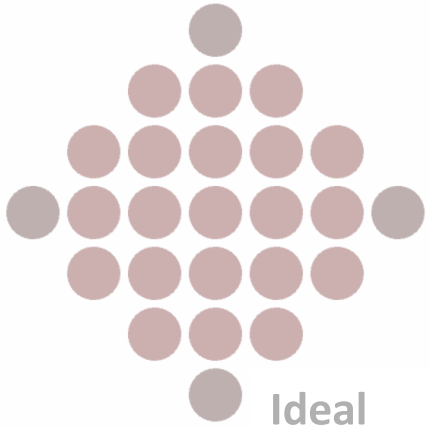


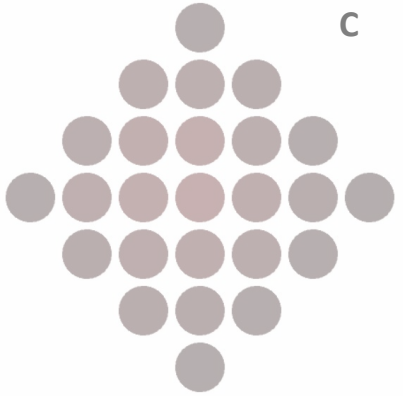


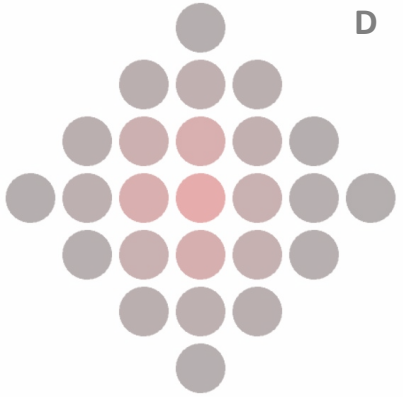




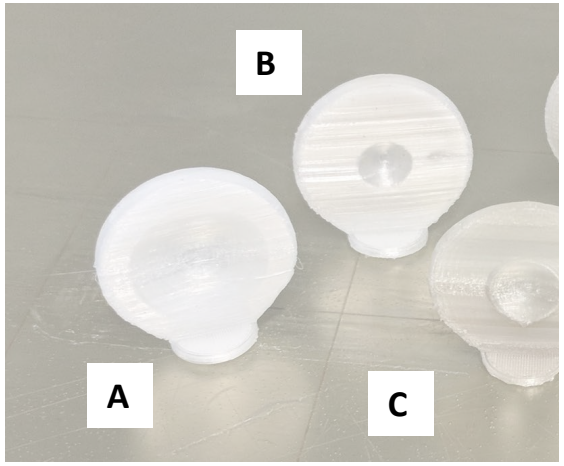


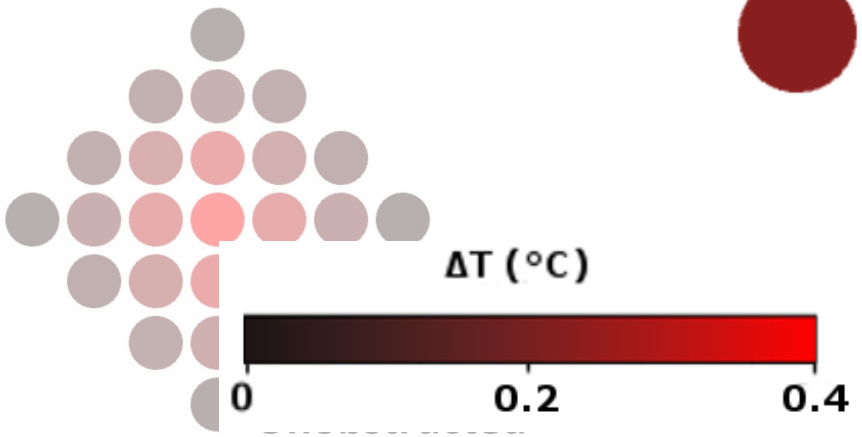


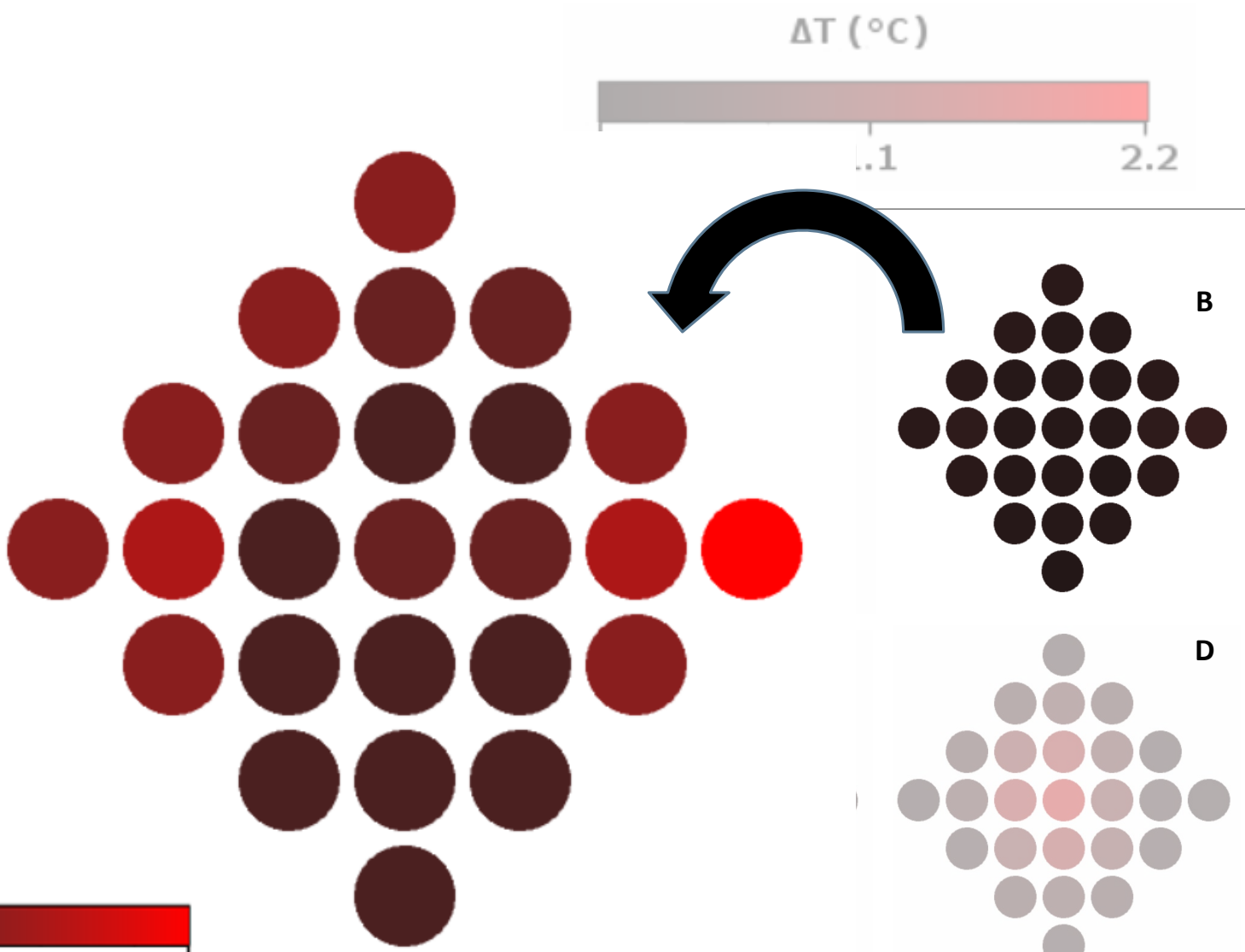




Kel-F lense







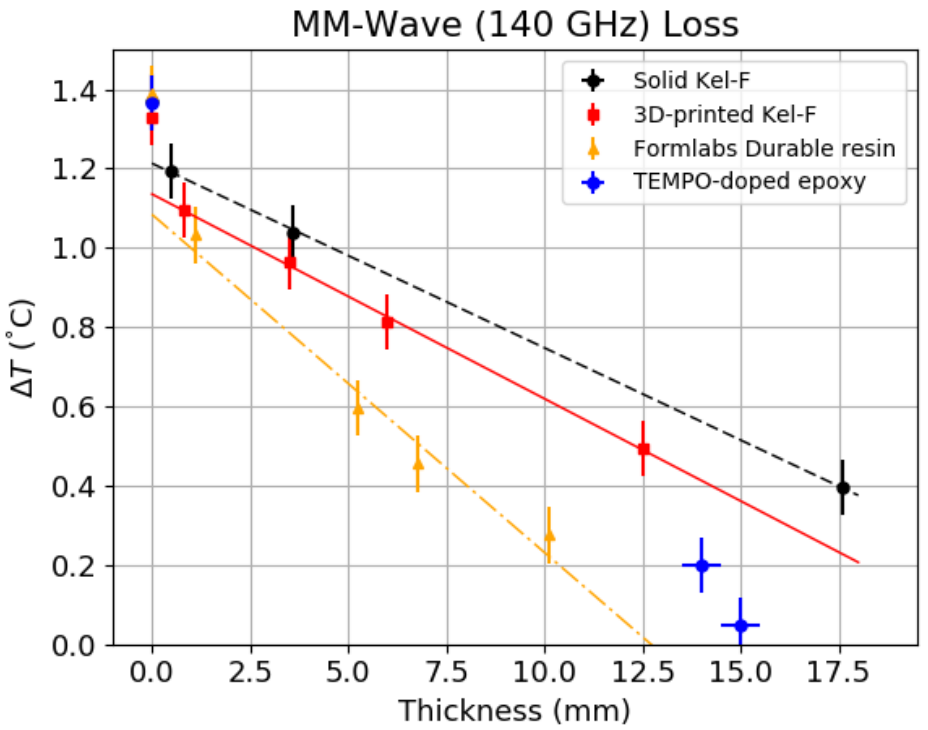
Kel-F lenses

Loss mechanisms:

Kel-F lenses

Loss mechanisms:

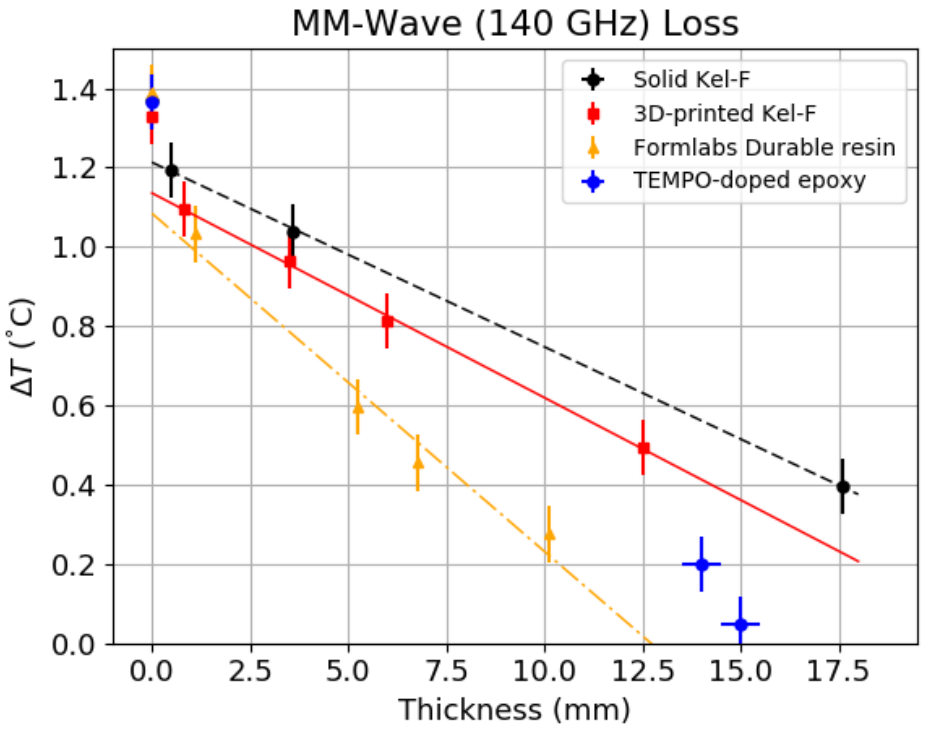
1. **Absorption**



Kel-F lenses

Loss mechanisms:

1. **Absorption**
2. **Surface reflection**



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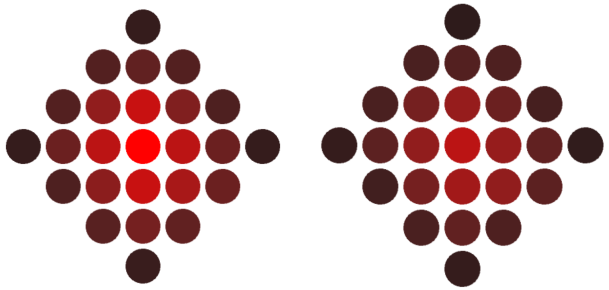
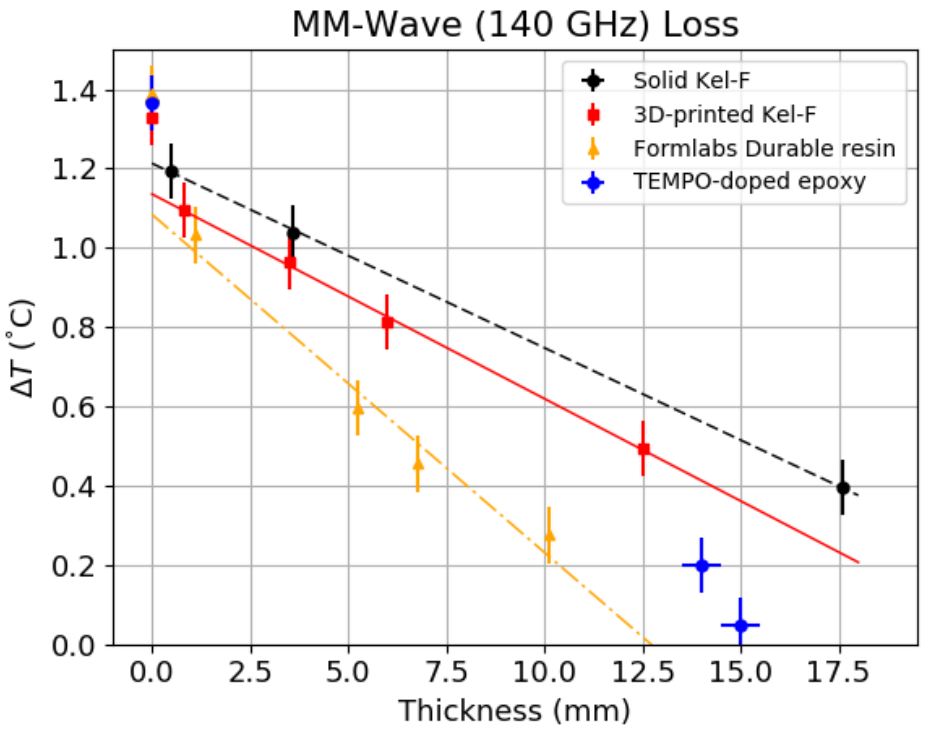


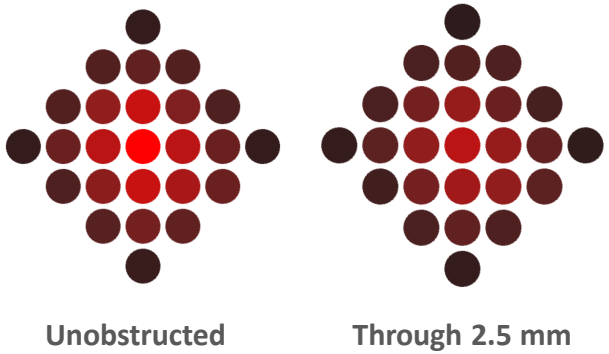
Unobstructed **Through 2.5 mm**



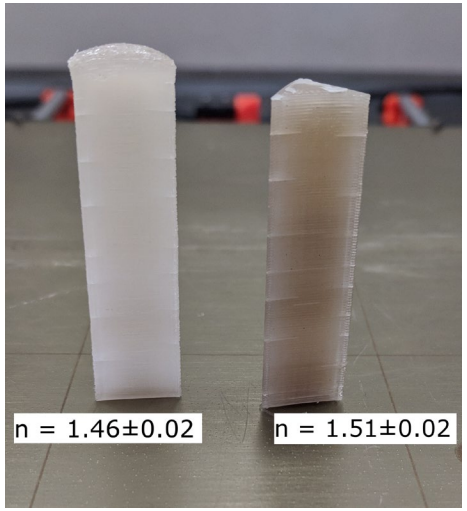
Kel-F lenses

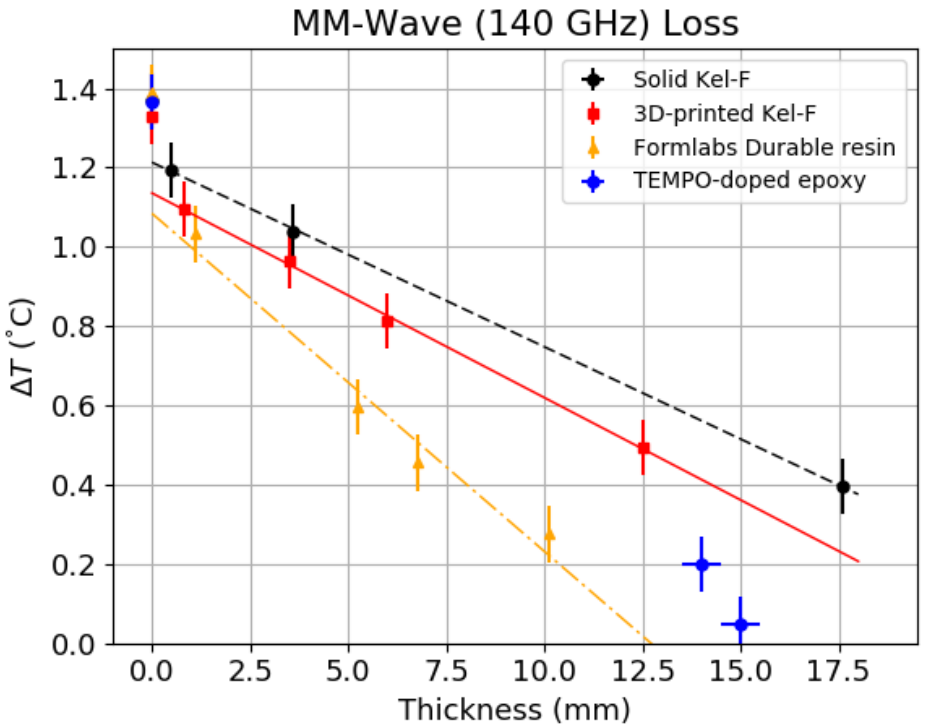
Loss mechanisms:

1. **Absorption**
2. **Surface reflection**
3. **Non-constant refractive index**



Unobstructed Through 2.5 mm

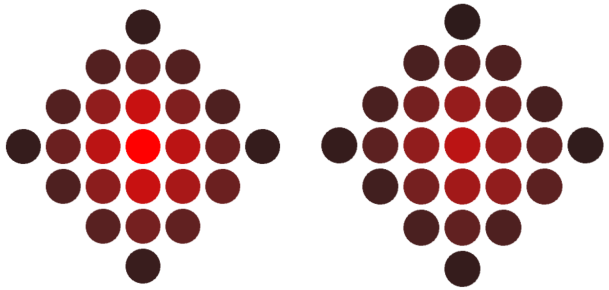




Kel-F lenses

Loss mechanisms:

1. **Absorption**
2. **Surface reflection**
3. **Non-constant refractive index**
4. **Diffraction ???**



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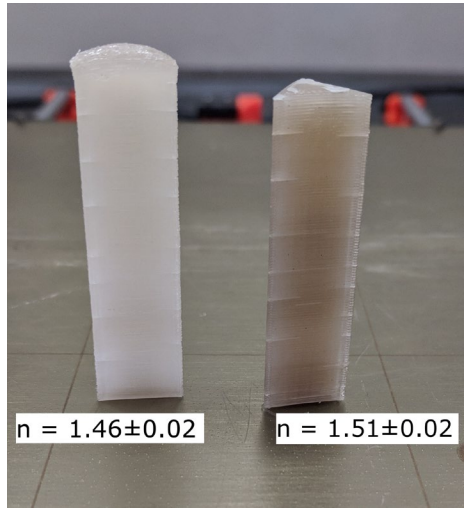

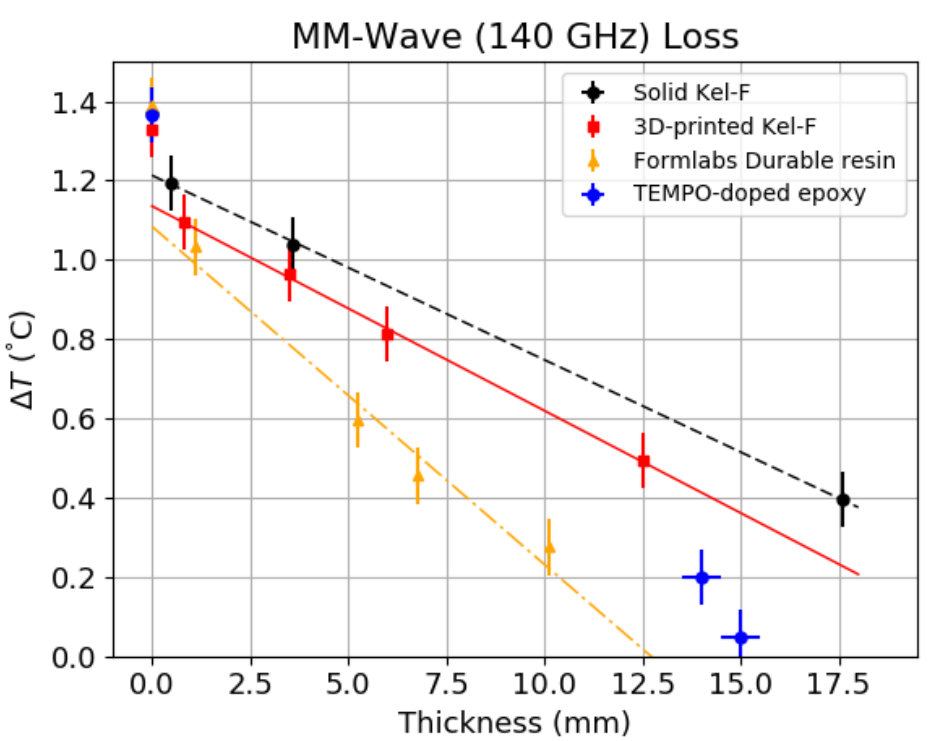

Kel-F lenses

Next steps:

1. **Continue investigating properties of lenses: focal plane, hot-spot ring**
2. **Model expected results based on known losses to better assess lens performance**
3. **Perform further analysis of lens results: can results be attributed entirely to absorption/reflection losses and hot-spot spread?**
4. **Experiment more with Fresnel lenses to minimize absorption losses**
5. **Devise lens mount for easier alignment (lenses are very difficult to center on beam)**

Thank you

My deepest appreciation to Professor Elena Long for her mentorship over the past 2 years.

Tristan Anderson
Prof. Maurik Holtrop
Lucas Jameson
Ryan McGuire
Ronny Nguyen
Tony Rogers
Nathaly Santiesteban

…and the UNH physics faculty. Thank you!!