Transmissive Final Optic for Laser IFE

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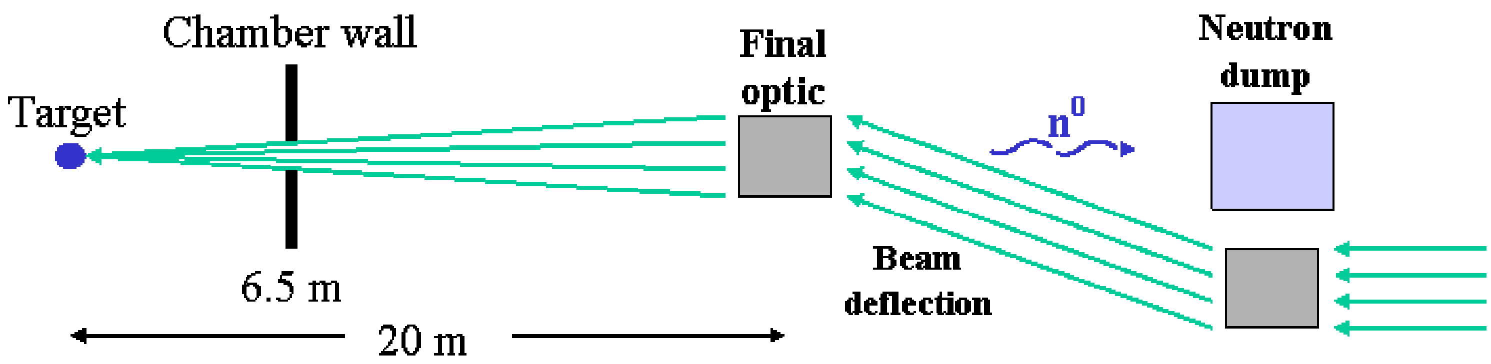
We have completed our study of the fused silica final optic (FO) option for 0.35 μm light, based on a "thin" Fresnel lens

Goal is to define the "operating window" for thin SiO_2 FO solution:

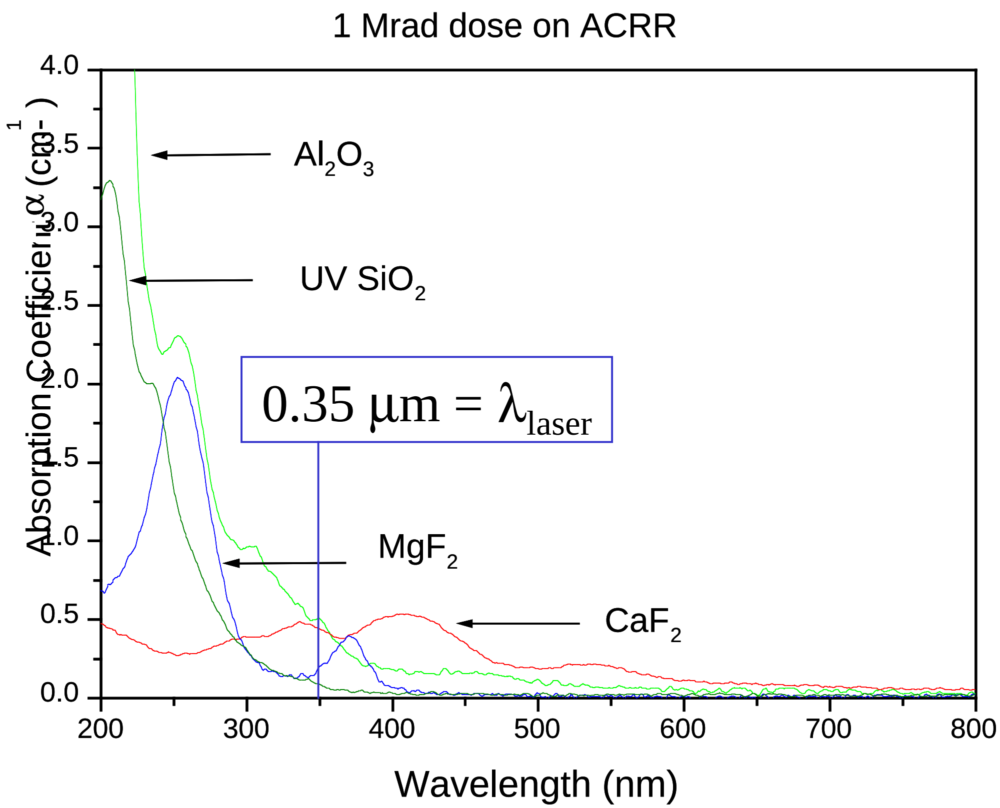
- Comparison of SiO_2 with other robust optical materials
- Effect of neutrons and gammas on optical properties
- Thermal management of laser heating with radiative cooling
- Accommodation of focusing, beam deflection, and smoothing



Several additional issues may need to be addressed:

- Transient response to neutrons (LANL)
- X-ray ablation of the surface
- Ion sputtering of the surface
- Shrapnel from the target

We have directly compared the absorption at 0.35 µm produced by 1 Mrad of neutrons for SiO_2, MgF_2, CaF_2 and Al_2O_3 (ACRR, Sandia)

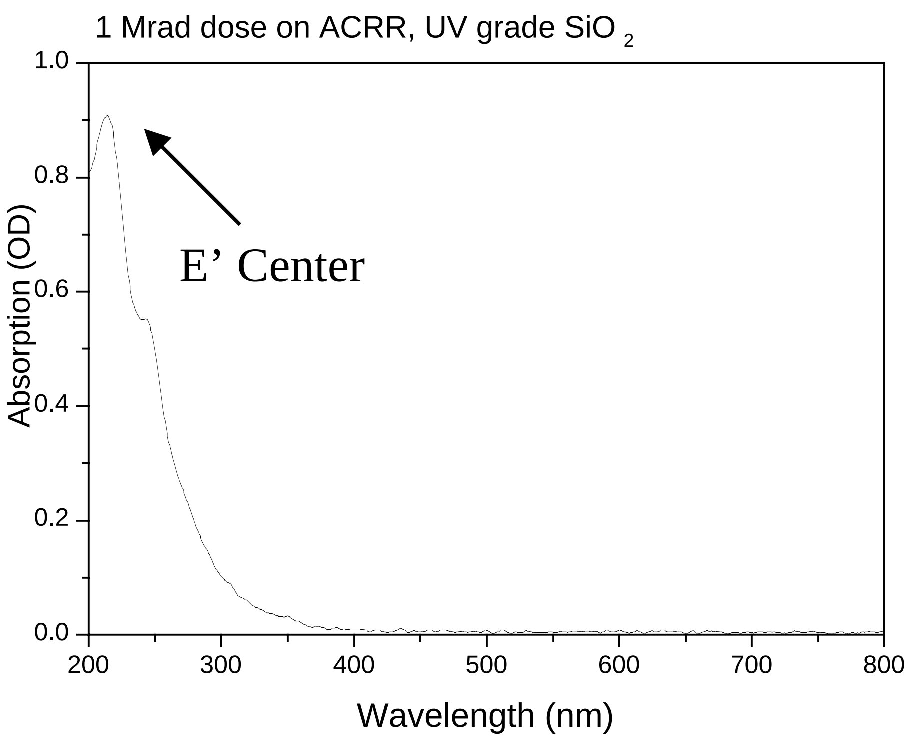


Optical Material	Absorption at 0.35 µm, α(cm^{-1})
SiO_2	0.03
Al_2O_3	0.45
MgF_2	0.15
CaF_2	0.45

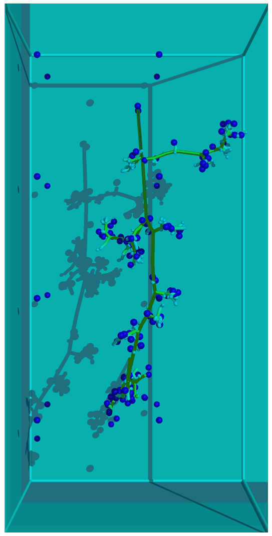
- SiO_2 yields *least absorption* at 0.35 µm for given neutron dose

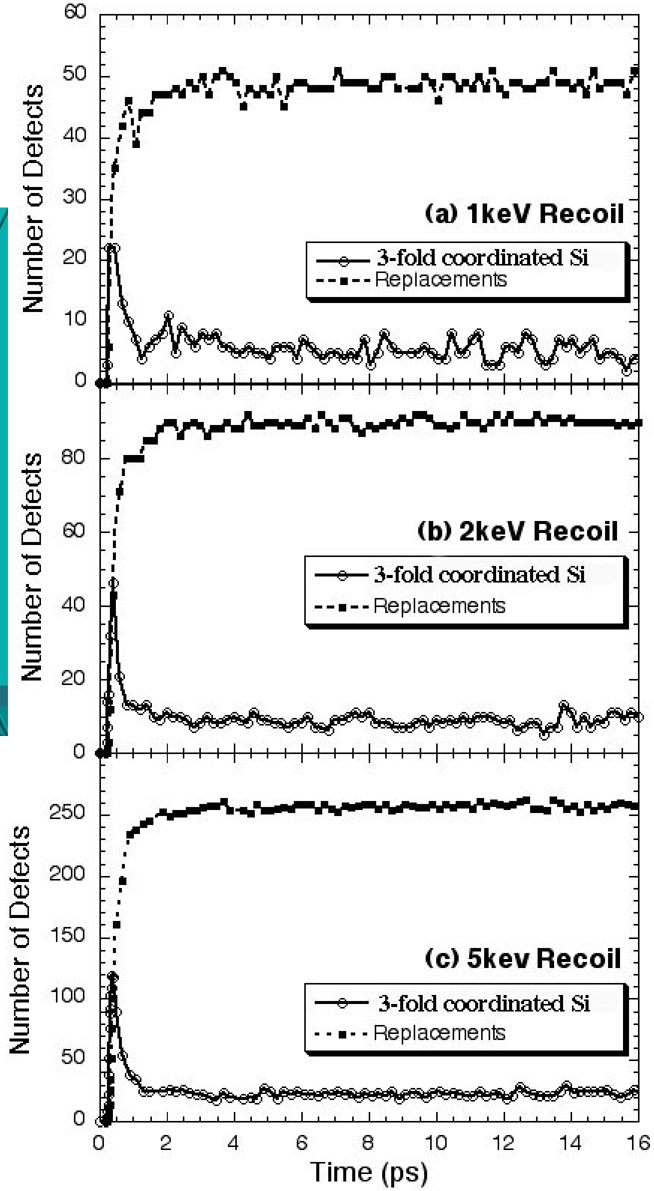
Neutron-induced defect formation has been studied by Molecular Dynamics Simulations (MDS) and absorption spectroscopy

Absorption spectrum (1 Mrad)



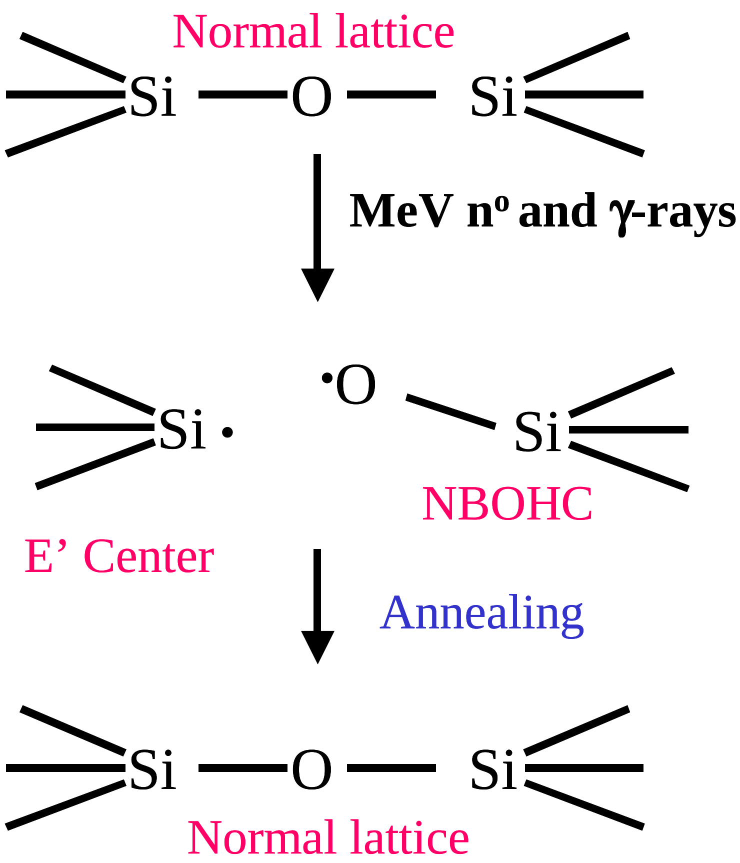
MDS





- Experimentally, 35 defects are created per 1 MeV neutron collision
- Based on MDS, ~ 400 are predicted
- Difference due to "slow" (>psec) recombination

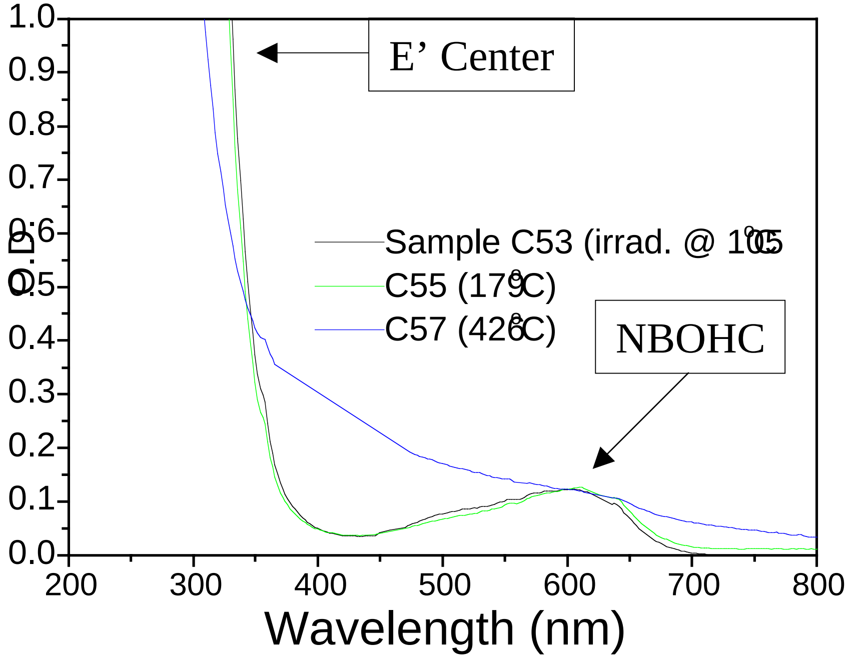
Simple mechanism of defect creation and annealing is supported by several observations



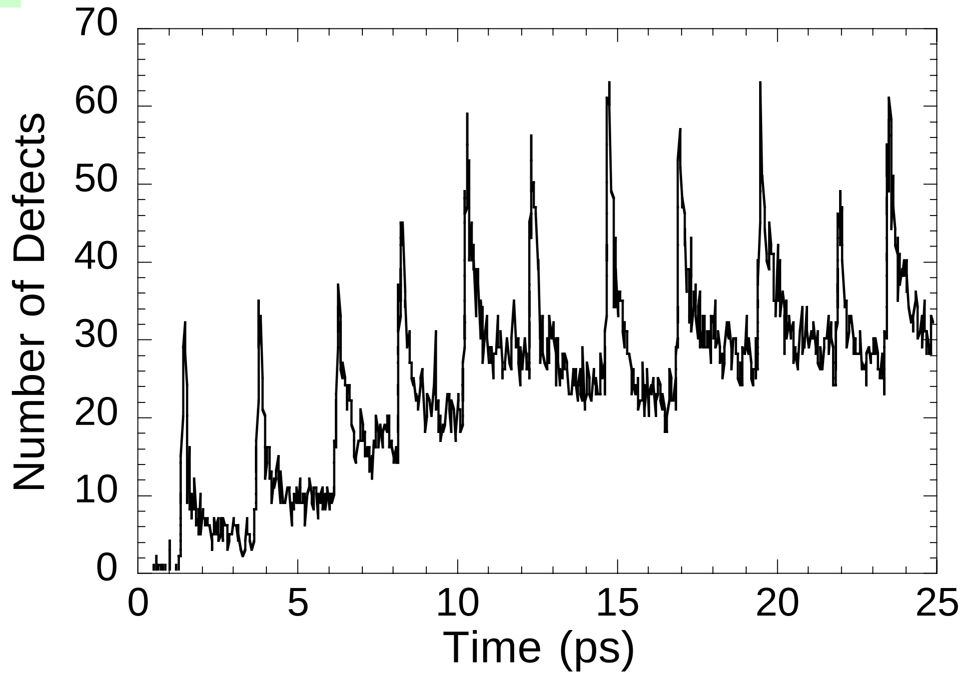
- Spectra of E' and Non-Bridging Oxygen Holes Centers (NBOHCs) observed
- E' centers and NBOHCs are formed in nearly equal number
- *Complete* elimination of defects by thermal annealing is possible
- Model is consistent with Molecular Dynamics Simulations

We have observed “radiation-annealing” in an optical material for the first time

SiO_2 samples irradiated at LANSCE for 10^{11} rad



Multiple recoils in same location (MDS)



• “Low dose” (1 Mrad) results, on prior vugraph, indicate 35 defects are formed per 1 MeV neutron collision

• “High dose” (10^5 Mrad) results, above, suggest 0.007 defects / collision

•Hypothesis is that overlapping collisional cascades give rise to “**radiation annealing**”

• Molecular Dynamics Simulations (MDS), above, reveal defects saturate after 5 cascades

As test of our radiation-annealing theory, measured and calculated collisional cascade volumes are compared

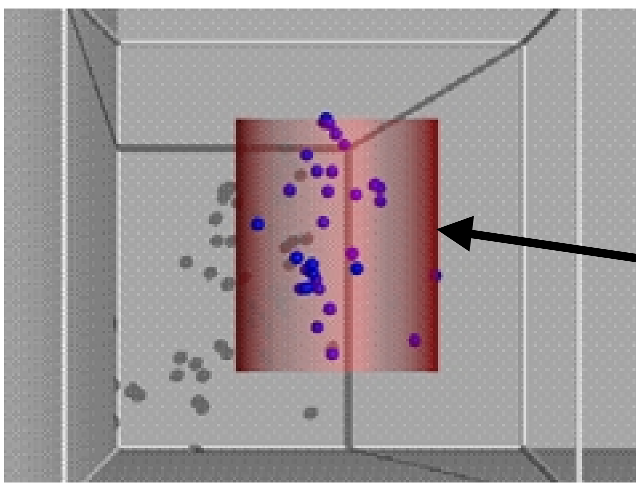
"Measured" volume of collisional cascade:

$$N_{sat} = M_n / V_{col}$$

Saturated defects, 1.8×10^{18} cm^{-3}

35 defects created per 1 MeV neutron

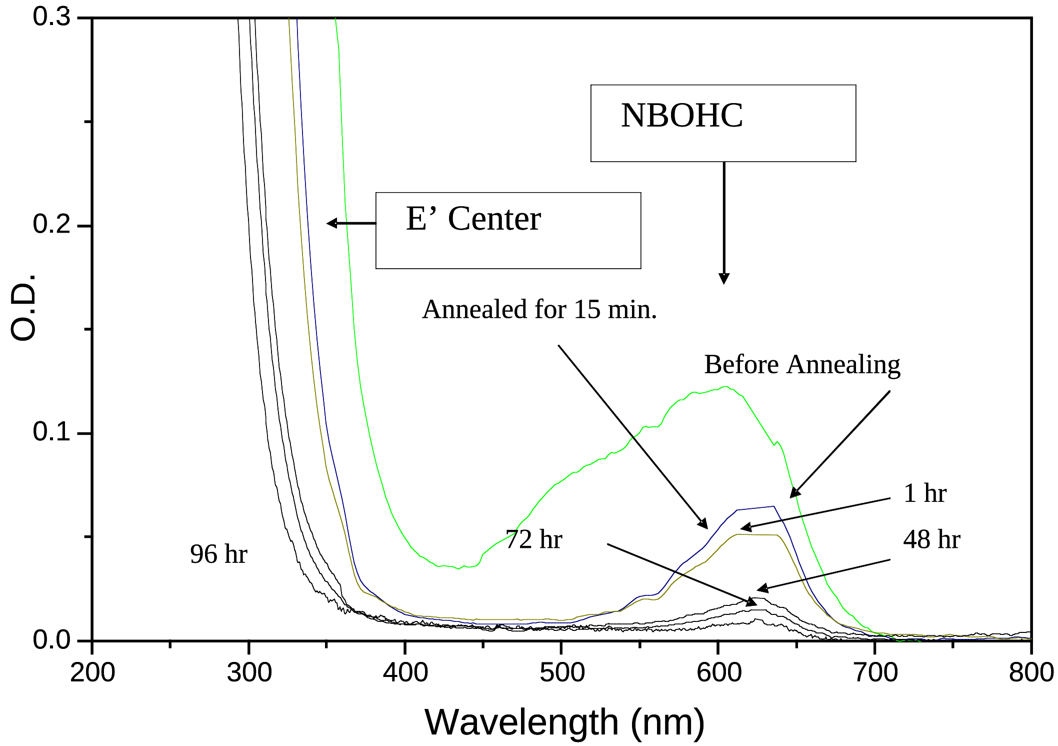
Collisional cascade volume, 1.9×10^{-17} cm^3

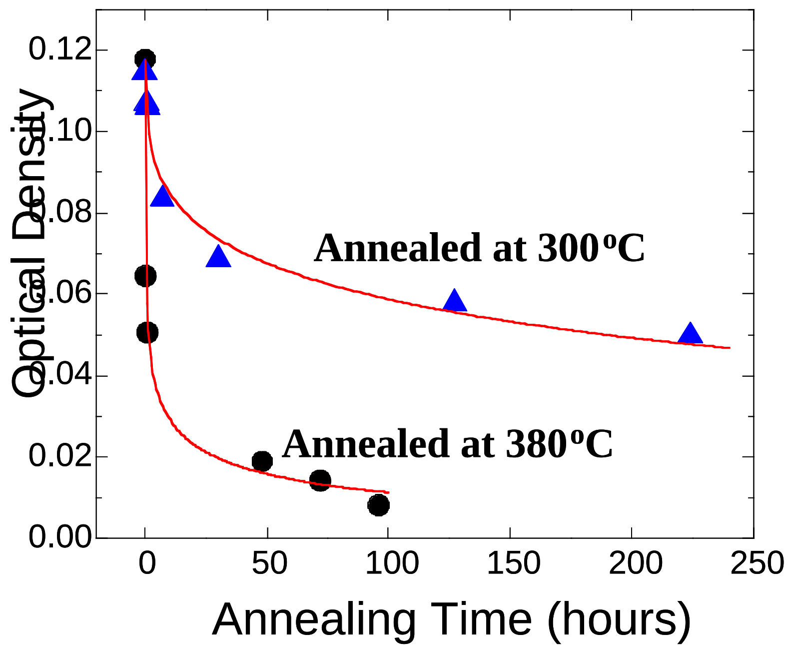


- Measured: V_{col} = 200 nm^3 per 1 keV recoil
- Theory: 200 nm^3 "box" is compared with distribution of defects from MDS

Annealing of defects has been quantified at two temperatures

Reduction in absorption from annealing at 380 °C

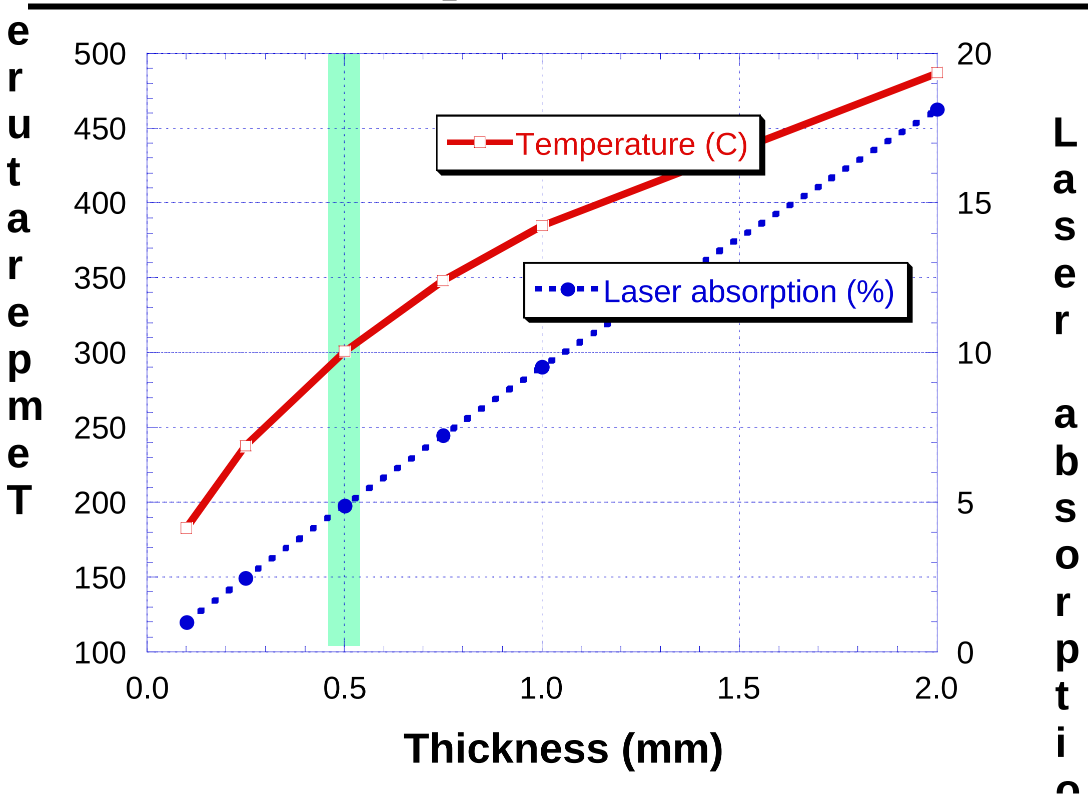




Fit to: $\tau_{anneal} = \tau_0 \exp(+T_{anneal} / T)$

- $T_{anneal} = 21{,}000\ ^oK$ and $\tau_0 = 4 \times 10^{-10}$ sec

Final optic must be < 0.5 mm thickness to avert excessive losses or temperature rise



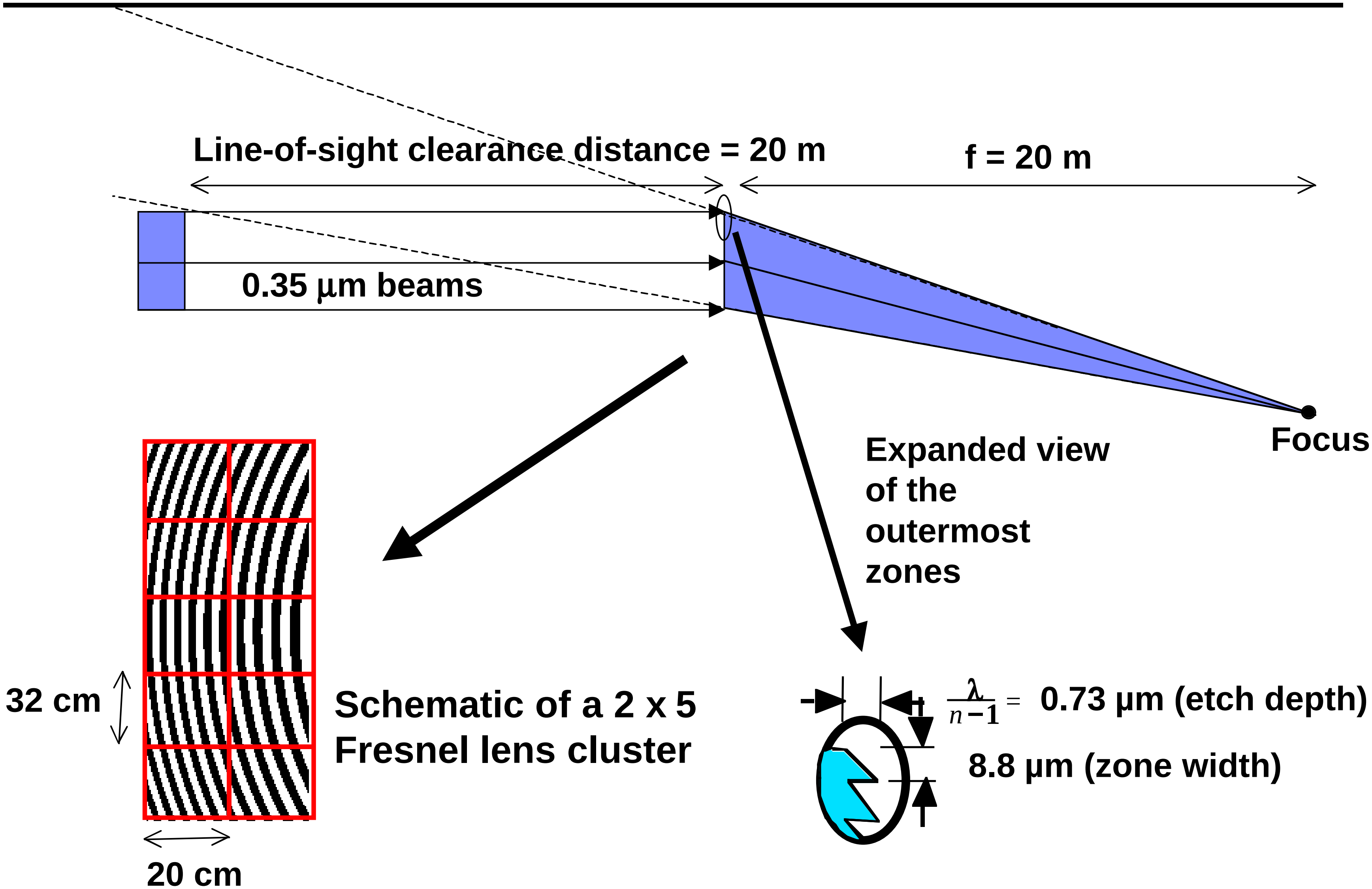
Based on radiative cooling with 0.5 mm thickness:

- $T = 300^oC$
- $f_{abs} = 5\%$ absorption

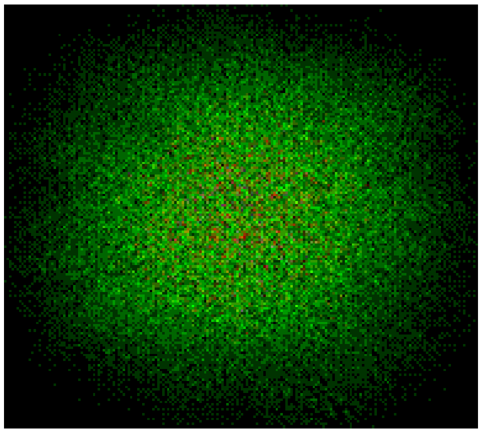
Cooling from one-side only (most conservative) has no effect on focus (second order effect – Ω_{bend}^2):

$$\Omega_{bend} = \alpha_{exp}\ f_{abs}\ F_{laser}\ \nu_{rep}\ d_{optic} / 2\ \kappa = 0.5\ \text{mrad}$$

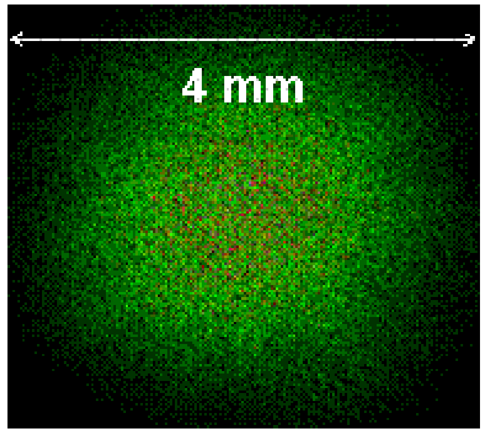
Final optic design is off-axis Fresnel lens for focusing and deflection



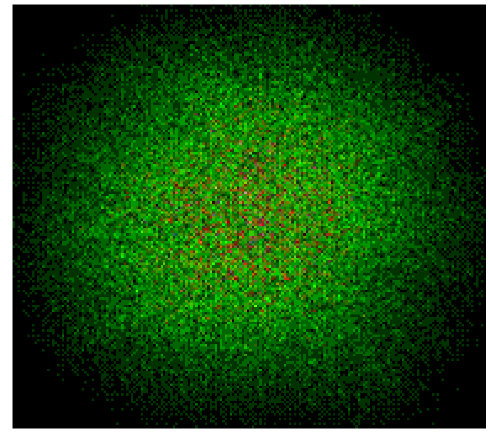
Combination of Fresnel lens and phase plate to yield spot size of ~3 mm for direct drive target



15 mm before focus



At focus



15 mm after focus

- Calculation includes effects of 1 THz bandwidth
- Calculated transmission efficiency is 99 % for linear grooves

Description of neutron-induced defects for SiO_2 under IFE conditions

Temperature of optic, T_{SiO2} = 300 ^oC:

- $Q_{heat} = \alpha_{abs}\, d_{SiO2}\, F_{laser}\, \nu_{rep} + F_{view}\, \sigma\, [T_{cham}^4 - T_{SiO2}^4]$
- $Q_{cool} = \varepsilon\, \sigma\, [T_{SiO2}^4 - T_{surr}^4]$

Annealing time, τ_{anneal} = 916 hrs:

- $\tau_{anneal} = \tau_0\, d_{SiO2}\, \exp[T_{anneal} / T_{SiO2}]$

Defect Concentration, N_{defect} =1.8 x 10^{18} cm^{-3}:

- $dN_{E'}/ dt = M_n\, (\sigma_n\, N_{SiO2})\, \phi_n\, [(N_{sat} - N_{E'}) / N_{sat}] - N_{E'} / \tau_{anneal}$

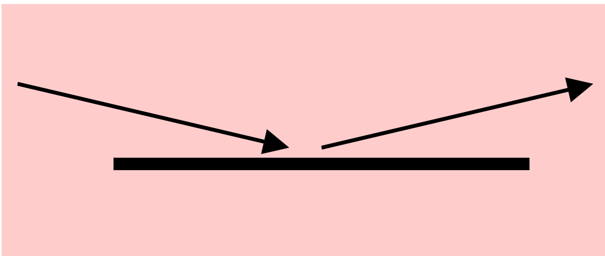
Laser absorption, $f_{abs}(0.35\mu m)$ = 5%

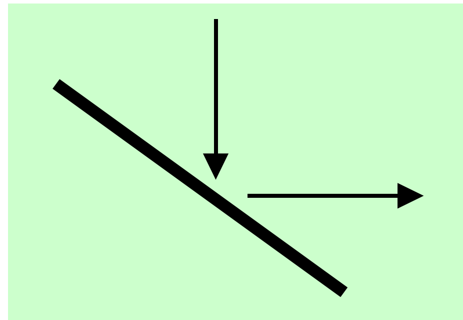
- Thinner optic would be advantageous

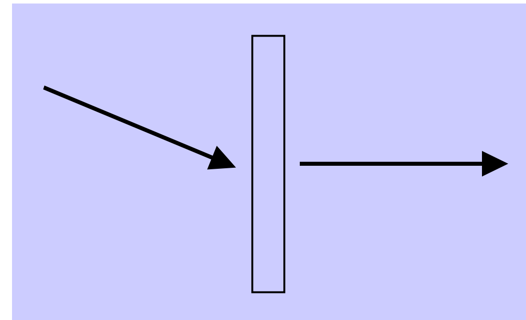
Summary of IFE deployment issues for off-axis Fresnel lens

Issue	Amelioration
Absorption of 10%/mm	Thickness of <0.5 mm
Scatter loss of 0.6 %/mm	
Heating of optic	
Fabrication	1 mm easy, 0.5 mm achievable, 0.25 mm possible
Density increase (saturates at 2.6 %)	Pre-treat optics to radiation
Avoiding optical damage	Laser fluence of ~1.5 J/cm^2
Optical bandwidth (1 THz)	Minor effect on focus
Misalignment / bending	

Aluminum mirrors, dielectric mirrors, and transmissive optics are all candidates for the IFE final optic







Aluminum mirror
- <10 nm evanescent wave
- grazing incidence
- 3ω and 4ω

Dielectric mirror
- ~10 μm "optical depth"
- arbitrary reflection angle
- 3ω and 4ω

Transmissive optic
- ~ 0.5 mm path length
- few degree deflection
- 3ω only

Radiation hardness studies of <u>dielectric mirrors</u> are planned
- Common constituents are SiO_2, ZrO_2, HfO_2, Ta_2O_5, MgF_2
- HfO_2, Ta_2O_5 are neutron absorbers, and become highly radioactive
- High damage threshold SiO_2 - ZrO_2 mirrors planned for irradiations
    - predict 0.2 rem / hr after 100 Mrad dose on HFER at ORNL