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Studies on thin films as short pulse laser debris shields

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Motivation:

- High energy, high power laser systems require large aperture off-axis parabolas for final focusing.
- These optics can be rather expensive (≈ $ 250k) and therefore need to be shielded from target debris.
- In the case of Z-Petawatt / Z Beamlet firing into the Z Accelerator additional Z-pinch debris needs to be considered.

Debris shield requirements:

- For high energy short pulse lasers one has to consider nonlinear effects in the debris shield, such as self-phase modulation, self-focusing and beam breakup.
- The severity of these effects is expressed in the B-Integral: $B = 2\pi/\lambda \int I\, n_2\, dL$, where λ is the laser wavelength, I is the laser intensity, n_2 the nonlinear index of the material, and L the thickness of the material.
- It is therefore desirable to keep the debris shield thickness as low as possible while maintaining good surface quality and good transmission characteristics.
- In addition the debris shield needs to tolerate high fluence levels (≈ 1 J/cm^2) and should have mechanical rigidity to withstand z-pinch debris.

Debris shield candidates:

- We investigated the following three films as possible options for debris shields:

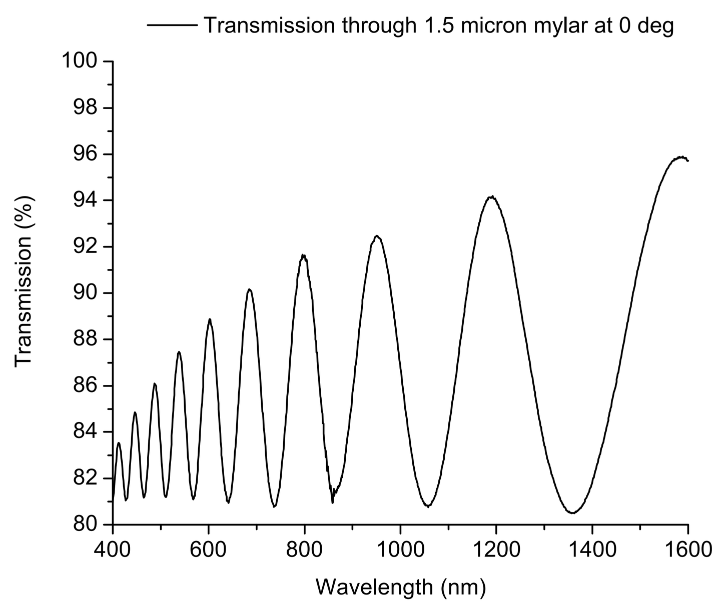
1. Nitrocellulose, thickness 4 - 4.5 micron, aperture 15 cm x 30 cm, n=1.51
2. Mylar, thickness 1.5 micron , aperture 15 cm x 30 cm, n=1.64-1.67
3. Polyimide, thickness 0.5 micron , aperture 17.8 cm (7'') diameter, n=1.76

- The following optical properties were investigated:

1. Spectral transmission characteristic from 400nm – 1600 nm.
2. Wavefront quality after double pass transmission through the film.
3. Stress induced birefringence
4. Damage threshold
5. Angular tunability for maximum transmission

Mylar

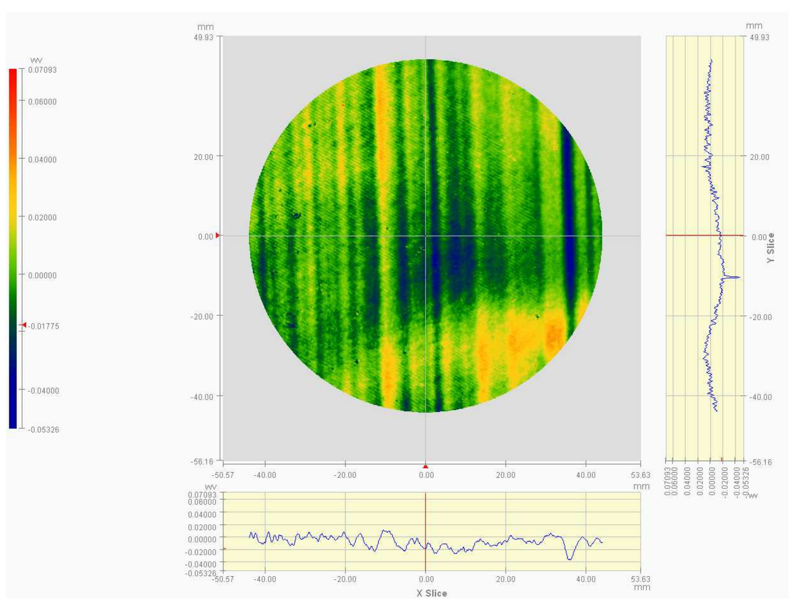
Spectral Transmission



The spectral transmission curve shows an interference pattern typical for thin films.

One can clearly see that Mylar exhibits an increased absorption towards shorter wavelength.

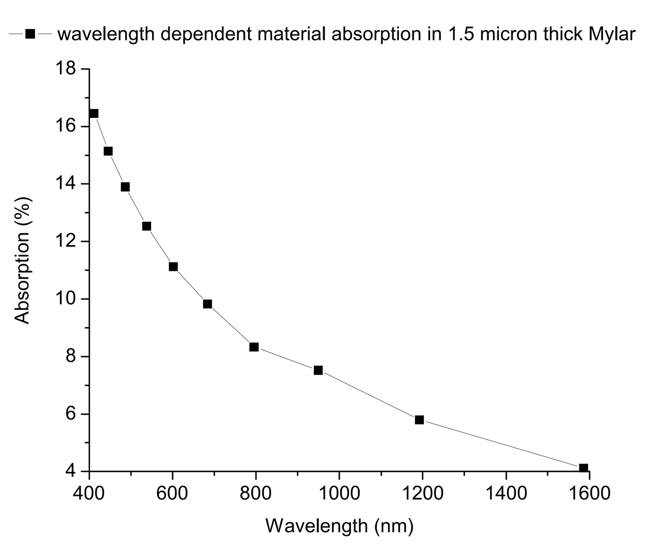
Optical Transmission Measurement



PV: 0.0664 waves
RMS: 0.0122 waves
Strehl: 0.994

⇒ Transmission characteristics seem quite good. However the periodic grating like behavior is of concern.

Absorption Measurement



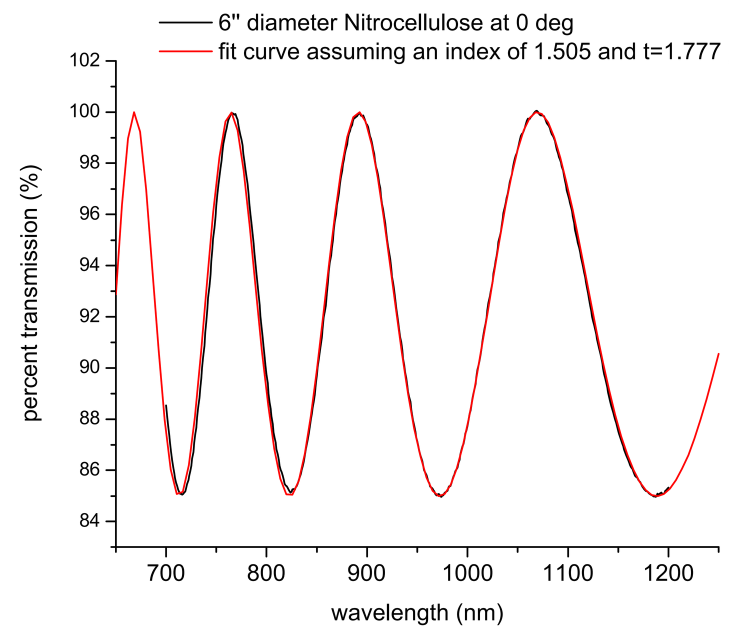
Material absorption is quite high. The lowest value of 4% is still above the highest absorption of 2.5% in nitrocellulose.

Summary:

- Although Mylar shows very good transmission characteristics, its absorption at 1054 nm is too high to be considered as a viable laser debris shield.
- **Therefore we have done no further studies on Mylar.**

Nitrocellulose

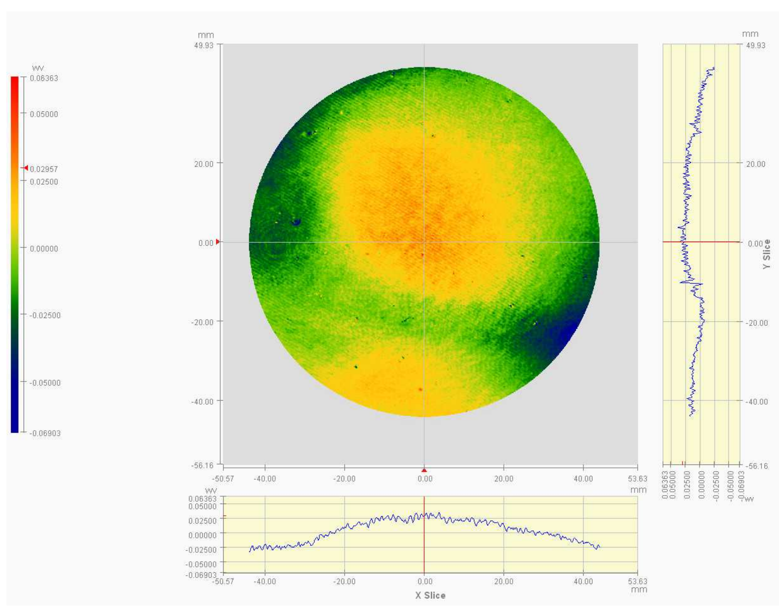
Spectral Transmission



The theoretical prediction fits well with the data, using n=1.51 and a thickness of 1.78 micron.

The variation of the maxima and minima are due to material dispersion. The transmission is on the order of 100% over the range of 750-1200nm.

Optical Transmission Measurement

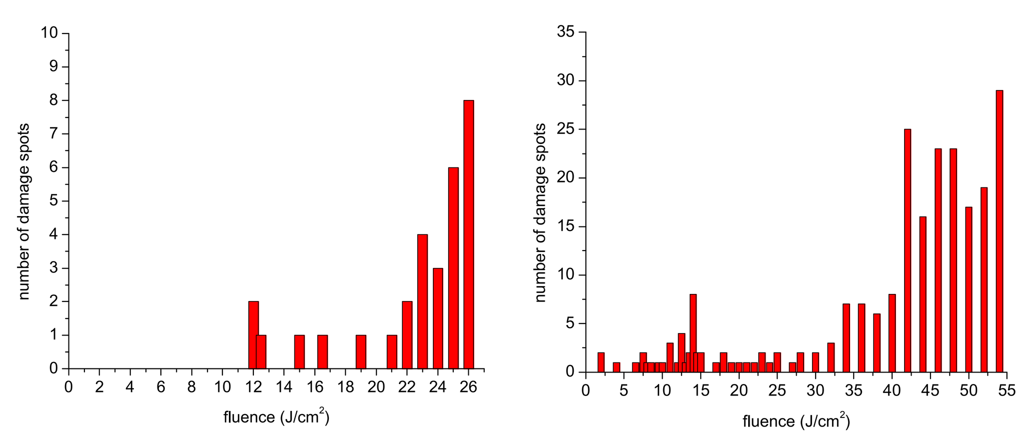


PV: 0.0724 waves
RMS: 0.0155 waves
Strehl: 0.991

⇒ Minimal wavefront distortion in double pass transmission

Laser Damage Testing

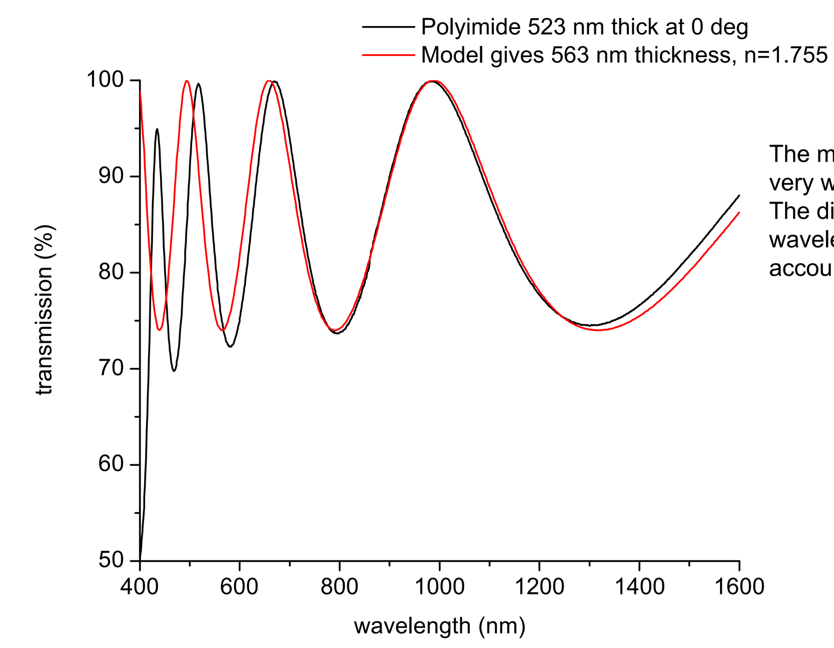
Spica damage test results:



- Preliminary tests in the 100 TW target chamber show that the film can survive a fluence of 150 mJ/cm^2 at 1 ps pulsewidth at 1054 nm.
- Spica test results at 3.5 ns and 1064 nm show no damage up to 11.5 J/cm^2 and non propagating damage up to 40 J/cm^2 (26 J/cm^2).
- 10 shot damage test indicated a 30% lower damage threshold than single shot tests. However, this could still lie within the "margin of error".

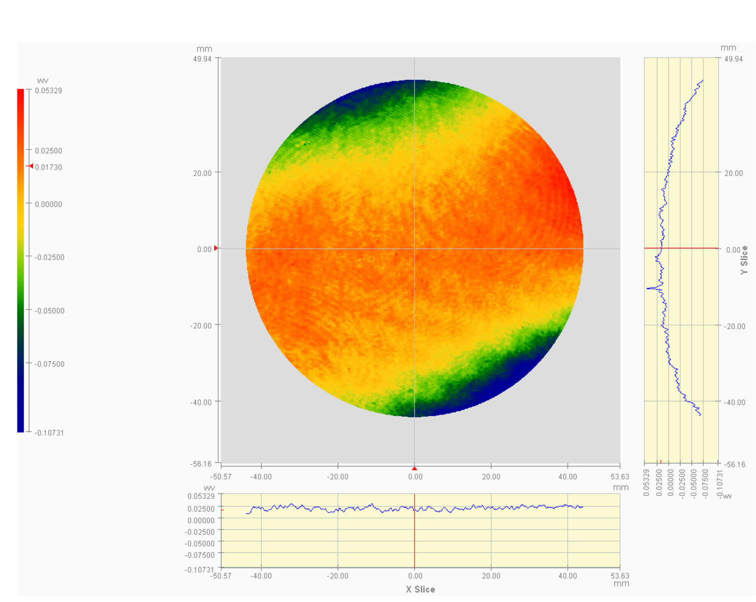
Polyimide

Spectral Transmission



The model fits the data very well around 1054 nm. The discrepancy at lower wavelengths is due to un-accounted dispersion.

Optical Transmission Measurement

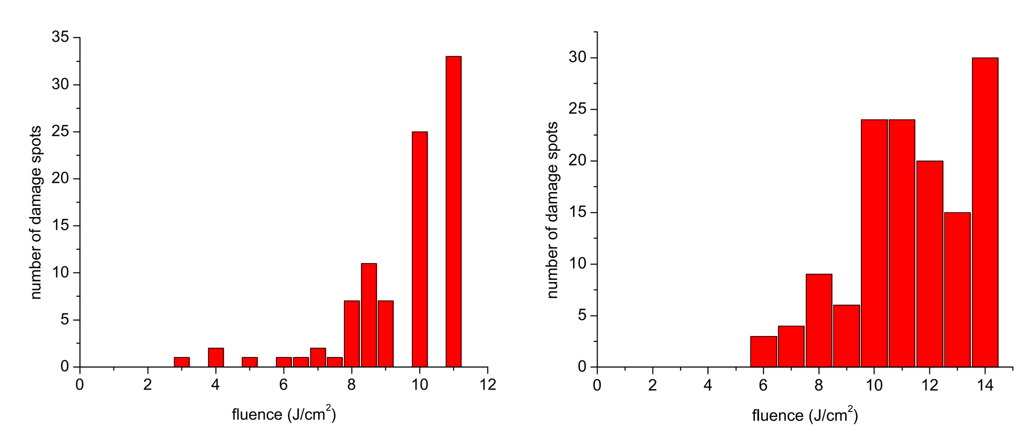


PV: 0.13 waves
RMS: 0.0266 waves
Strehl: 0.972

Double pass transmission is slightly worse than previous samples. However, it is still very good.

Laser Damage Testing

Spica damage test results:

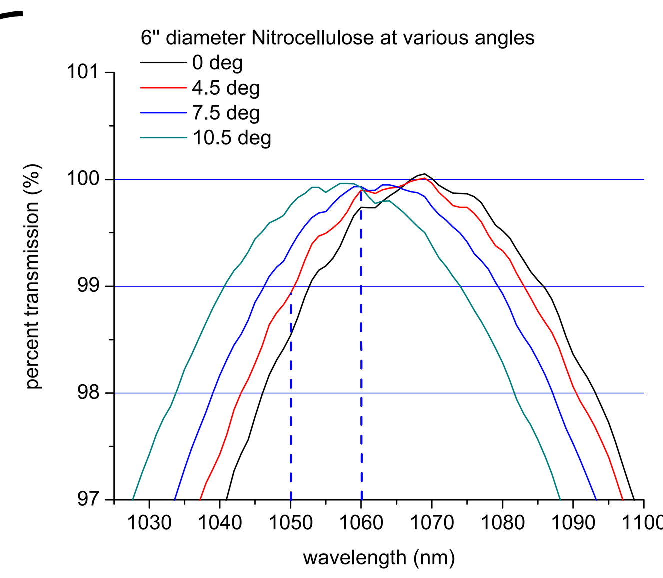


- Spica test results at 3.5 ns and 1064 nm show no damage up to 2.5 (5) J/cm^2 and non propagating damage up to 20 J/cm^2.
- 10 shot damage test indicated a 30% lower damage threshold than single shot tests. However, this could still lie within the "margin of error".

Results:

- Nitrocellulose and Polyimide both show excellent wavefront transmission characteristics and low absorption.
- Nitrocellulose exhibits a factor of two higher damage threshold and can achieve better thickness control for large scale fabrication. It also has a wider transmission bandwidth for our design points.
- Therefore Nitrocellulose is our material of choice for short pulse laser debris shields!
- A 17'' diameter pellicle is now being fabricated for first backlighting experiments on the Z-Accelerator.

Prototype Fabrication (Nitrocellulose)



Spectral Photometer trace for a 6'' Nitrocellulose pellicle at various angles of incidence.

For a laser bandwidth of +/- 5nm around 1054 nm center wavelength the transmission is > 98.9 %.

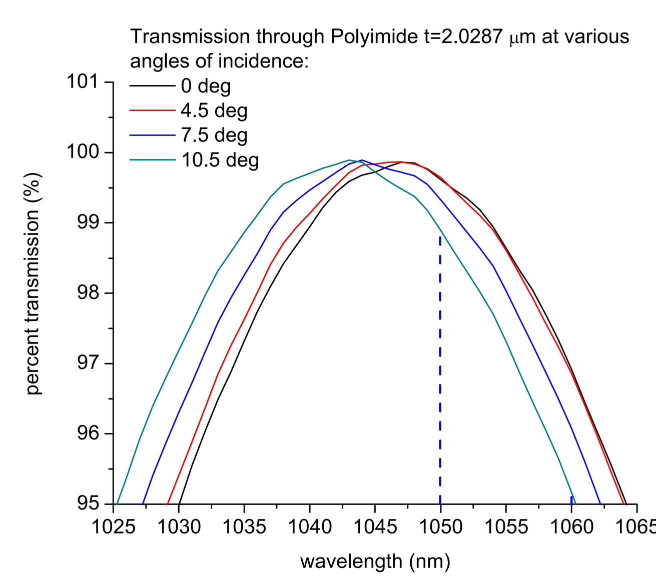
Summary:

- absorption too low to measure
- excellent wavefront in transmission
- no stress birefringence
- good damage threshold
- scalable to large aperture, 15cm x 30cm demonstrated
- transmission can be maximized by taking advantage of interference in thin films

Challenge:

- Can the film be manufactured at large size (17'' diameter) with the required Δt ?

Prototype Fabrication (Polyimide)



Attempted thickness:
t = 2.06 +/- 0.01 μm

Actual thickness:
t = 2.0287 μm

One can clearly see that the shift in film thickness leads to an offset in the maximum transmission peak.

For a laser bandwidth of +/- 5nm around 1054 nm center wavelength the transmission is > 95 %.

Summary:

- absorption < 0.12%
- excellent wavefront in transmission
- no stress birefringence
- good damage threshold
- scalable to large aperture, 7'' diameter demonstrated
- transmission can be maximized by taking advantage of interference in thin films

Challenge:

- Can the film be manufactured at large size (17'' diameter) with the required Δt ?

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Z Petawatt

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