Durability of Ultrathin Foils in the FLASH Beam

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Damage of ultrathin foils in the FLASH beam was observed under fluences of about 10^{12} photons in a ~1mm diameter beam. Typical examples are shown in Figure 1.

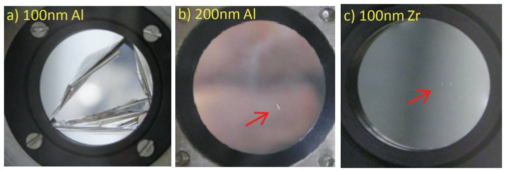

Figure 1: 16mm aperture ultrathin foils after exposure to the FLASH beam
a) 100nm Al, 1 pulse, 6nm photons, 100µJ, 1.5mm beam diameter *result:hole and tear*
b) 200nm Al, 7nm photons, 30 pulses x 10µJ/pulse x 1µsec interval, 0.5mm diameter, total dose ~10^7 pulses *result:hole*
c) 100nm Zr, 13nm photons, 30 pulses x 100µJ/pulse x 1µsec interval, several mm diameter, total dose ~10^7 pulses *result:discoloration spots*

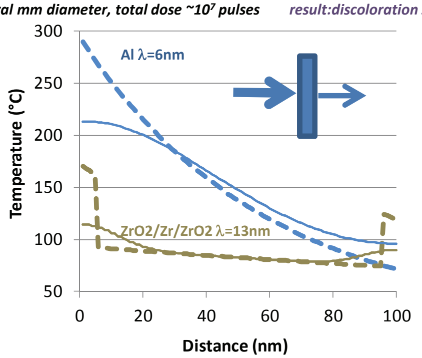

Figure 2: Dashed traces: Peak temperature versus distance for 100nm thick ultrathin foils exposed to a single 10µJ pulse (0.5mm x0.5mm). Top trace is 100nm thick Al exposed to 6nm photons. The bottom trace is a 100nm Zr film which has 5nm of native oxide on front and back surfaces. Solid traces are the temperature profiles after 10^{-3} µsec.

Qualitatively, the damage can be understood by considering the instantaneous energy absorption of the FLASH pulse by the foil. Figure 2 shows calculated temperature profiles immediately after the passage of a 10µJ pulse, for a 100nm thick aluminum foil and for a 100nm thick Zr foil with a 5nm thick ZrO2 on each surface. Notable features are:

- The leading surface can be much hotter than the average through-thickness temperature
- The outer surface temperatures can be very high due to impurities.
- The through foil equilibration time is about 1-10 nsec, orders of magnitude slower than the FLASH pulse.

To screen potential filter materials without the mass absorption coefficients and thermal properties of each candidate material, a simple thermal model for has been derived. If the Dulong-Petit heat capacity is assumed, the surface temperature rise due to an incident X-ray pulse is given by

$$\Delta T = \frac{2 r_e hc}{3k} N_p \bar{f}_2 \qquad (1)$$

where r_e is the classical radius of the electron, h is Planck's constant, k is Boltzmann's constant, c is the speed of light, N_p is the local number of photons per unit area, and $\bar{f}_2$ is the imaginary atomic scattering factor averaged over the local foil stoichiometry. Substituting, equation (1) becomes

$$\Delta T = 2.702E^{-13} cm^2 K \; N_p \bar{f}_2 \qquad (2)$$

Table 1 shows surface temperatures for potential filter materials for 1×10^{19} photons/cm2 pulses at two energies. Figure 3 shows temperature rise vs. photon energy for Mo.

	6nm ΔT (K)	13.5nm ΔT (K)
Al	2202	1867
Zr	1140	292
Mo	640	303
Pd	905	1516
Polyimide	88	222
Carbon	77	188
ZrB2	1095	160
ZrN	648	340

Table 1: Peak surface temperature for ultrathin foils exposed to 3E12 photon pulses(0.5mm x0.5mm) for two wavelengths.

For pulse trains separated by 1µsec, it is expected that a 100nm film will adiabatically equilibrate between pulses, but radiative cooling will only happen over several milliseconds.

Typical Time Scales	Seconds
FLASH pulse duration	1E-14
Through-Foil Thermal Equlibration	1E-8
Flash interpulse spacing	1E-6
Foil Radiative Cooling Time	1E-3
Flash Intertrain spacing	1E-1

Table 2: Time scales for various foil and beam processes

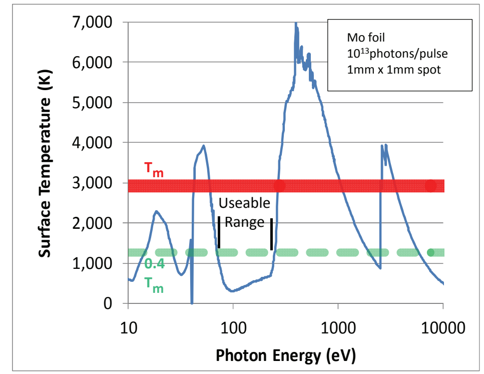

Figure 3: Expected surface temperature rise versus photon energy for an ultrathin molybdenum filter, compared with the melting temperature (Tm). Thermal fatigue is expected to be minimized below 0.4T_m.

500nm Zr foil mounted "loosely" on TF111-frame. 13nm photons, 300 pulses x >5µJ/pulse x 1µsec interval, 1mm diameter *(discoloration, no hole)*

Several foils were prepared for general filter use in the 100eV to 250eV range. Results to date are:

200nm ZrB2: No holes developed in several months of use. Spots and surface deformations formed.

100nm Pd/100nm Polyimide (Pd towards beam): No holes formed, but black spot formed over time at the beam site. Possible polyimide degradation.

Zr: Discoloration, but no through-holes created.

The following recommendations appear beneficial for foils placed in the free electron beam:

- Materials with low average f_2, high melting temperature, and good fracture toughness are desirable.
- For layered films, the most refractory material should face toward the incident beam.
- Films should be mounted "loosely" on the frame[5] to mitigate tear propagation (e.g. see image at right).

REFERENCES

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