Adhesive-free Zirconium Mesh and ZrB_2/Zr Ultrathin Membranes

Bruce Lairson, Dave Grove, Heidi Lopez, Travis Ayers

Luxel Corporation, Friday Harbor, WA

EUV optical systems often require membranes in the light path to block unwanted radiation, debris, and contamination. However, these membranes must have high transmission at 13.5nm, must not compromise imaging, and survive intense power and bombardment conditions. We propose an ultrathin, Zr-based membrane, supported by a Zr-based mesh, to satisfy overall system requirements for such a filter.

Here, we demonstrate two basic elements: 1) Lithographically patterned Zr mesh which is semitransparent to the EUV radiation, and 2) a ZrB2/Zr layered structure with 20nm total thickness. The combination of these or similar structures can enable optical elements such as pellicles, spectral purity filters, debris shields, etc.

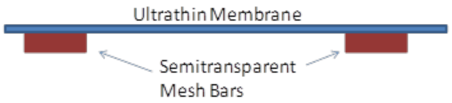

Figure 1. Proposed adhesiveless membrane/mesh geometry.

The figure above shows the desired structure for a pellicle. No adhesive exists between the mesh bars and the membrane. The membrane is ideally ultrathin, 25nm or less, and composed of materials with low13.5nm absorption. Here we propose a composite membrane composed of ZrB2 and Zr. The mesh bars are ideally made from a material with good strength and low EUV absorption. Table 1 shows these desired mesh and membrane characteristics. The composite transmission goal is >90% at 13.5 eV.

Table 1: Desired Mesh Dimensions

Zr Mesh Bar Width	1-2 microns
Zr Mesh Bar Thickness	100nm-200nm
Zr Mesh Pitch	100-300 μm
Avg. Mesh Transparency	96%-99.7%
Desired Membrane:	
Zr/ZrB2 composite thickness	20nm
Membrane transmittance	>90%

Possible Pellicle Design	Zr Mesh	20nm Zr/ZrB2 Membrane	Zr/ZrB2 membrane +Zr Mesh
Transmission	+	+	+
Burst Strength	-	-	+
Crack mitigation	-	-	+
Particle blocking	+	-	+
Power Density	+	-	+

Table 2: Advantages of the composite membrane/mesh structure

The mesh bars exist primarily for crack arrest. To successfully arrest a crack, the force propagating the crack tip must be less than the tensile strength of the bar. Applying Griffith's crack criterion, the bar thickness can arrest a propagating crack if the ratio of bar thickness to membrane thickness is

$$\frac{t_B}{t_M} > \frac{C}{\sigma_Y \sqrt{a}}$$

where t_B is the mesh bar thickness, t_M is the membrane thickness, C is the fracture toughness of the membrane, σ_Y is the yield strength of the bar, and a is the mesh pitch. For candidate materials, crack arrest can occur for $t_B/t_M>3$. Figure 2 shows crack arrest at a mesh bar for $t_B/t_M=3.3$

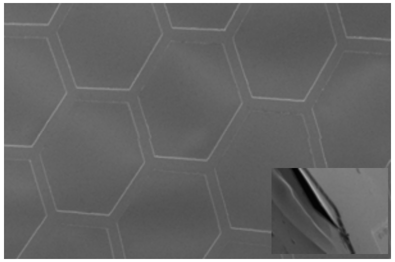

Figure 2. Patterned 1 micron Zr mesh on a 300nm Zr membrane. Inset: Membrane crack arrest at a mesh bar.

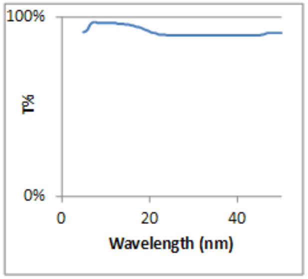

Figure 3. Modeled transmission spectrum for a 90% open, 100nm thick Zr mesh.

Figure 3 illustrates the desired mesh transmission characteristics. While the mesh is 90% open, the transmission at 13.5eV is higher due to reduced absorption at this wavelength.

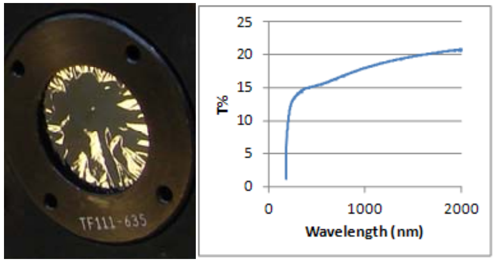

Figure 4: Meshless 4nm ZrB2/12nm Zr/4nm ZrB2 membrane on a 16mm aperture . Graph shows transmission in the wavelength range 190nm-2000nm.

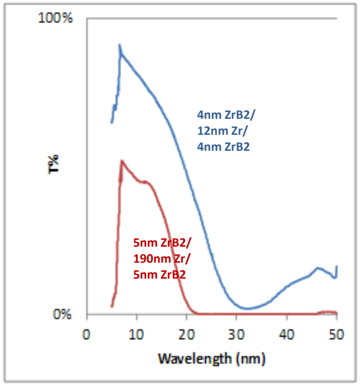

Figure 5. Measured EUV transmission of 4nm ZrB2/12nm Zr/4nm ZrB2 and 5nm ZrB2/190nm Zr/5nm ZrB2.

Figures 4 and 5 illustrate measured visible and EUV transmission for a candidate membrane material, with a total thickness of 20nm. While we propose a mesh support, the measured samples is a freestanding 20nm thick trilayer spanning a 16mm aperture. EUV transmission for the 20nm membrane is below our goal,likely due to oxidation in air.

We have illustrated mesh and membrane elements needed for a high transparency, mesh strengthened membrane. Future work will involve combining these elements into filters suitable for pellicles, debris shields, etc. for EUV optical systems

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