Ultraviolet Reflectance of Microporous PTFE

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Abstract

Porous PTFE (polytetrafluoroethylene) is an excellent material choice for a range of UV reflectivity applications because of its resistance to degradation, high reflectivity, and diffuse (Lambertian) reflectance. This paper presents the reflective properties of porous PTFE in the 250 nm to 500 nm range and correlates reflectance with porosity and thickness. Porous PTFE is a good option for integrating spheres, architectural lighting, photometry equipment, and LED applications, where the highly diffuse reflective properties of porous PTFE convert a narrow, directional light source into a wider illuminance.

Introduction

Ultraviolet radiation degrades many common polymer materials, such as polyethylene, polycarbonate, and nylon. Thus, common high reflectivity materials such as polyesters and polycarbonates are not generally used as UV reflectors. One commonly used material in these applications is aluminum, due to its high reflectivity, commercial availability, and machinability. While aluminum is useful for applications that require spectral reflectance, the metal does not produce a uniform Lambertian distribution of light[1]. Porous PTFE exhibits a near-perfect diffuse reflectance, resists degradation from UV light, can be molded into complex shapes, and is chemically inert, making it an attractive material for light spreading applications. The focus of this paper will be on sintered porous PTFE and the factors that influence its diffuse reflectance and transmission.

Background

Reflectance

This paper will address diffuse reflectance, as well as total reflectance, of microporous PTFE. The subsurface interactions between the light and the particles and pores of the material are largely responsible for its Lambertian scattering of light; surface roughness does not have as large of an effect. A Lambertian distribution of light refers to the ideal case of diffuse reflection on a surface and is characteristic of smooth matte surfaces on which the light distribution does not depend on the viewing direction of the observer[2].

Specular reflectivity, on the other hand, refers to the mirror-like reflection of incident light from a surface such that the angle of the incident light to the normal is the same as the angle of the reflected light to the normal. This type of reflection results in glossy or shiny surfaces. Some materials can exhibit both specular and diffuse reflection simultaneously. Total reflectance is the sum of diffuse and spectral reflectance and accounts for all energy that is not absorbed into or transmitted through the material[3].

Mercury Porosimetry

Mercury porosimetry can be used to measure the pore size distribution and pore volume (fraction) of a porous material. In this technique, a porous sample is placed in a vacuum chamber, air is evacuated, and mercury begins to fill crevices in the sample. Mercury, a non-wetting liquid, resists entry into the pores of the material due to surface tension. The pressure in the container is then slowly increased, and the volume of mercury permeating the material is closely monitored as pressure increases. Using Washburn's equation, a relationship between the applied pressure and the minimum pore size into which the mercury will enter can be calculated. Combining this data with the volume of mercury intrusion at each pressure provides information regarding the pore size distribution of the material as well as other material properties [4,5].

Sintering

Sintering is a process in which particles are fused together using heat and/or pressure to produce a cohesive porous solid. This technique allows for great control of factors of the output material, including its pore size and pore volume. Because the sintering process does not necessarily use a binder or adhesive, the end product can be pure and uniform due to the control of the input material. Sintering lends itself to molding a variety of shapes.

PTFE can be processed using several techniques, such as sintering, pressing, and stretching. This paper presents only porous sintered PTFE.

PTFE

PTFE is hydrophobic, and due to its carbon-fluorine bonds, it is chemically inert. PTFE's dielectric properties make it a good electrical insulator, and it has a low coefficient of friction. With a high melting point of 327°C, its functional temperature range exceeds that of many plastics. Thus, it is suitable for some high temperature applications[6].

UV Degradation of Plastics

UV radiation has the ability to ionize most plastics since the bonds between atoms in the plastics have dissociation energies that are similar to the quantum energies found in UV radiation, leading to scission of the carbon backbone[7].While the exact photochemical mechanism of UV degradation varies depending on the plastic, the general mechanism involves the material absorbing the UV energy and producing a free radical. Free radicals then propagate within the material and change the physical and mechanical properties of the plastic[8].

The resistance of PTFE to UV light can be partly attributed to the strength of the carbon-fluorine bonds found in the material. These bonds are roughly 30% stronger than a typical carbon-hydrogen bond found in plastics such as polyethylene or polypropylene. The Fluorine bonds surround the helical carbon backbone of the polymer, providing resistance to chemicals as well as photoionization. Furthermore, most fluoropolymers do not contain the trace amounts of chromophore impurities in their structure that often act as catalysts for photo-oxidation, which can occur in other plastics [9].

Methods and Materials

Test Procedure

The PTFE samples were tested using a Perkin Elmer Lambda 1050 Spectrophotometer with a 150 mm integrating sphere accessory. Using Spectralon® as the known PTFE standard, the total reflectance was measured with the sample mounted on the sphere. For the diffuse reflectance tests, a specular light trap was mounted on the sphere so that only diffuse reflection was measured. To measure transmittance, the sample was mounted at the port where the light first enters the sphere.

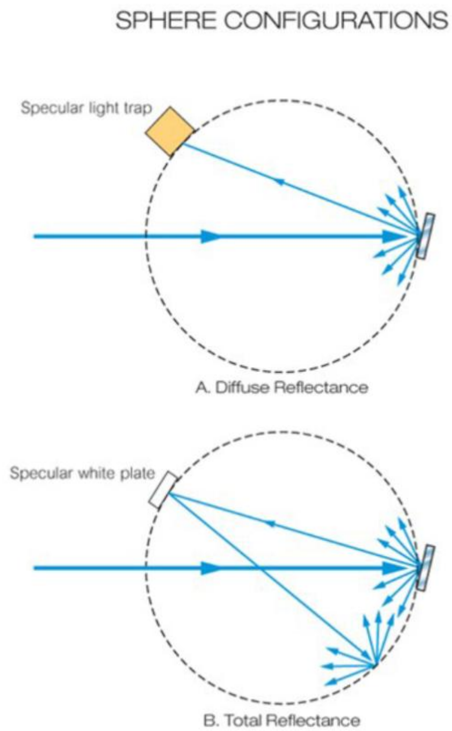

Figure 1: Reflectivity Test Setup.

Data Correction

Before measuring reflectance of the samples, a scan was run with Spectralon® to provide a reflectivity standard. All subsequent samples were then measured relative to this established standard. Since the absolute reflectivity of the Spectralon® standard is known, the sample data was corrected to provide the absolute reflectivity of each sample. The data presented in this paper is the true or "corrected" reflectivity values. They represent the absolute reflectivity of the PTFE material, not the reflectivity relative to the Spectralon® standard used in the initial scans.

Test Samples

Samples presented here consist of two types of sintered pure PTFE material. One set of samples were made by skiving after sintering, and the other set was made only by molding. Different pore sizes and thicknesses were included in the testing as shown in Table 1 and Table 2. The pore sizes vary from 1.8 micron to 27.2 microns, and the thicknesses vary from 0.5 mm to 2 mm. The samples are labeled as "S1, S2, S3, etc." and referred to in the paper as such.

Table 1: Skived Samples

Sample #:	Material:	Thickness:	Median Pore Diameter (µm)
S1	Pure PTFE	0.5 mm	1.8
S2	Pure PTFE	0.5 mm	2.3
S3	Pure PTFE	0.5 mm	4.6
S4	Pure PTFE	0.5 mm	6.4
S5	Pure PTFE	1 mm	1.6
S6	Pure PTFE	1 mm	2.1
S7	Pure PTFE	1 mm	3.7
S8	Pure PTFE	1 mm	5.9
S9	Pure PTFE	2 mm	1.8
S10	Pure PTFE	2 mm	2.1
S11	Pure PTFE	2 mm	4.6
S12	Pure PTFE	2 mm	6.3

Table 2: Molded Samples

Sample:	Material	Thickness	Median Pore Diameter(µm)
M1:	Pure PTFE	1.4 mm	6.8
M2:	Pure PTFE	1.3 mm	19.9
M3:	Pure PTFE	2.8 mm	27.2

Results and Analysis

Results from microporous PTFE material tests highlight a 97.4% average UV light reflectivity from 250 nm - 500 nm. The material that is used in all graphs, unless otherwise noted, is S10 which has a 2 mm thickness and a 2.1 micron pore size.

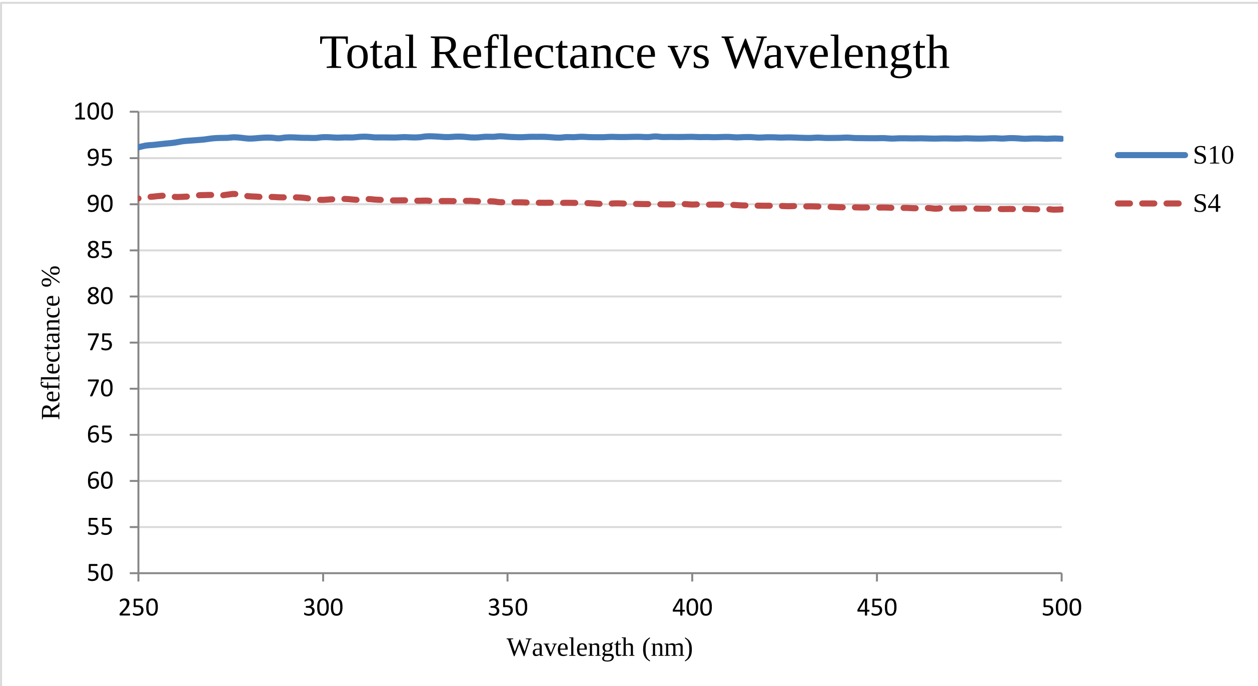

Figure 2: Total Reflectance. Sample 4 (Porous PTFE sheet at 0.5mm thickness) and Sample 10 (2 mm thick porous PTFE sheet) bracket the low and high UV reflectivity of the PTFE samples in the experimental set.

PTFE has low UV radiation absorption properties in the 250 nm to 500 nm range. Figure 3 depicts the sample with the lowest absorption across those tested, with values of less than 3.5%. At wavelengths below 240 nm, PTFE begins to absorb UV light as carbonification begins to occur on the surface layer of the material, and chemical bonds there are severed[10] .

For wavelengths longer than 250 nm, the absorption levels are low; most of the light is reflected while a small amount is transmitted through the material. In these experiments, we found that the microporous PTFE samples produced no measurable specular reflection of the incident light. Nearly all of the UV energy was reflected by the material is reflected diffusely.

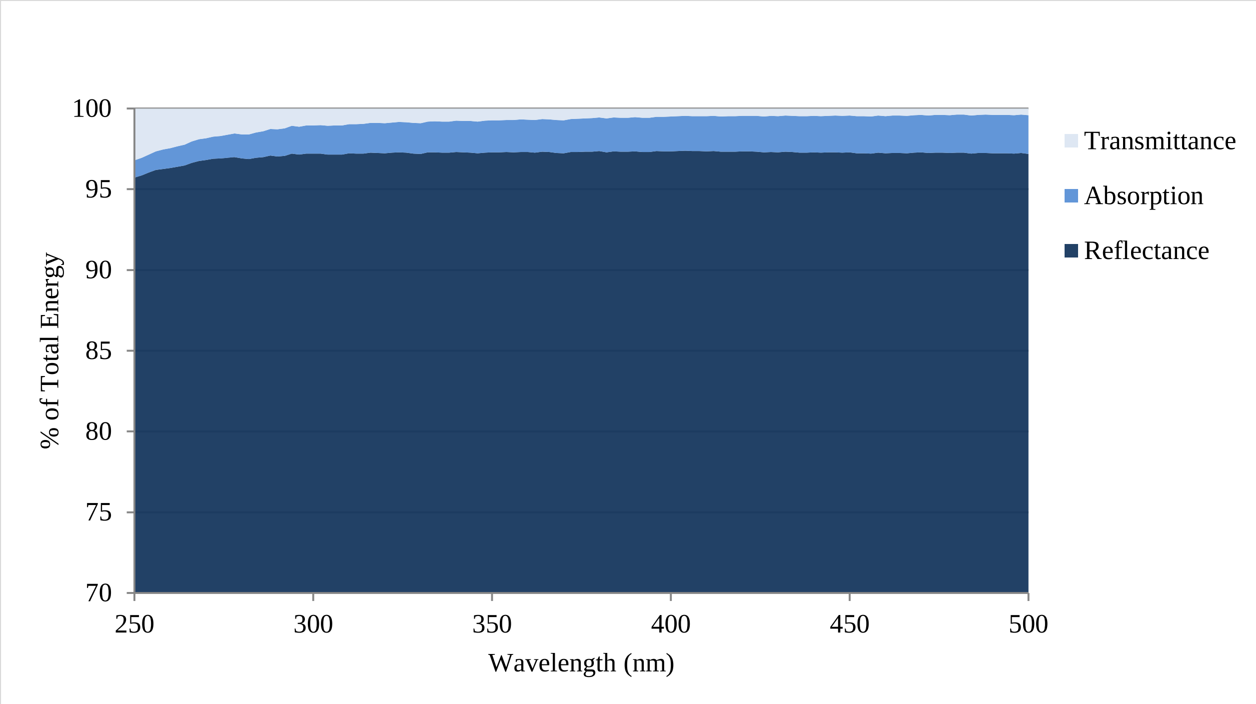

Figure 3: Transmittance, Absorption, and Reflectance as a function of wavelength.

Factors affecting Reflectivity: Thickness, Pore Size, and Other Correlations

The porosity of PTFE, relative to solid PTFE, can have a significant effect on a materials' reflectance properties. Porous PTFE sheet samples at 2 mm thickness showed a reflectivity over 97%, and we expect the reflectance of thicker samples to be even higher. These values compare to the reflectance of solid PTFE of 85-95% [12].

Within the range of pore sizes in this experimental set, the thickness of the material had the most significant impact on the reflective properties of PTFE. As seen in Figures 4 and 5, thickness has a direct relationship with reflectivity, and an inverse relationship with transmittance. Microporous PTFE sheet at 3 mm thickness exhibits total reflectance of over 99% in the UV and visible range, as well as close to 100% diffuse reflectance.

Thickness is a critical parameter because of the mechanism of diffuse reflection. A thicker material will cause the UV to have more reflections within the PTFE structure before the light is able to pass completely through the material. Conversely, more light will be transmitted through a thinner material than a thicker material. The inverse logarithmic relationship found in the transmittance data is supported by the work by B.K. Tsai on the Directional Hemispherical Transmittance of Sintered PTFE as a function of thickness, where the same trend was found to be independent of wavelength[6].

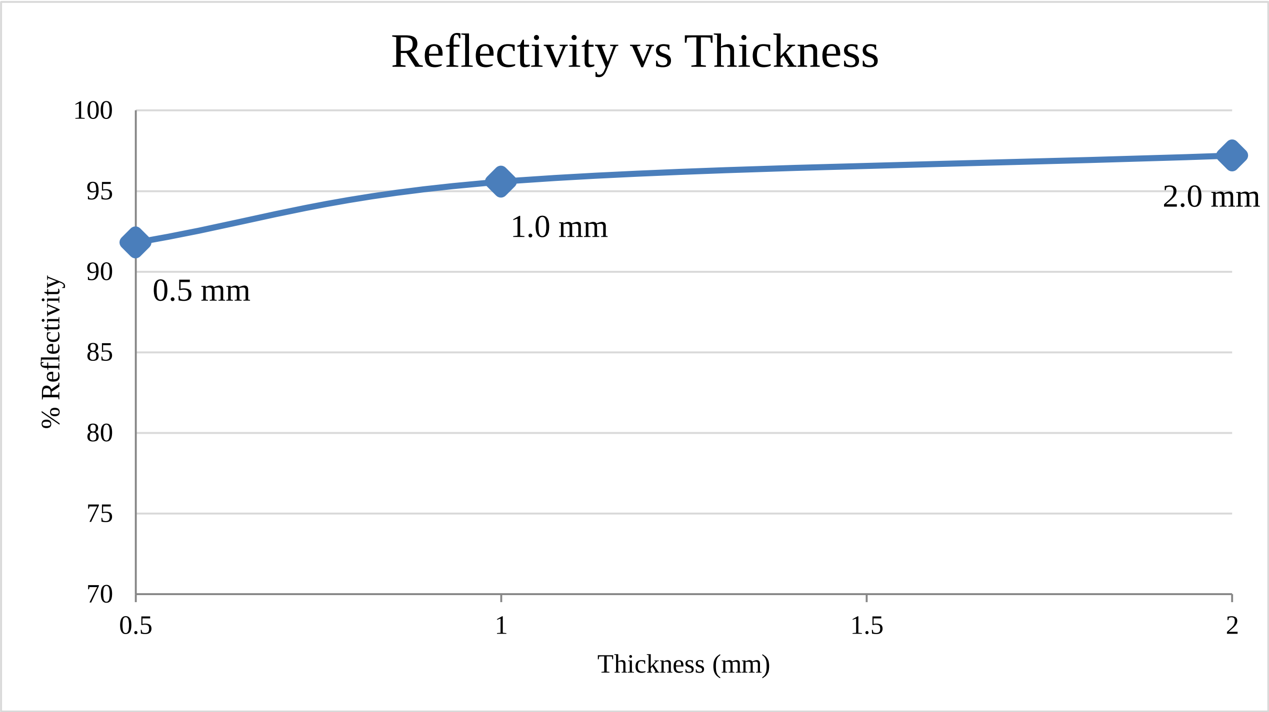

Figure 4: Reflectivity vs Thickness of Samples with the Same Porosity

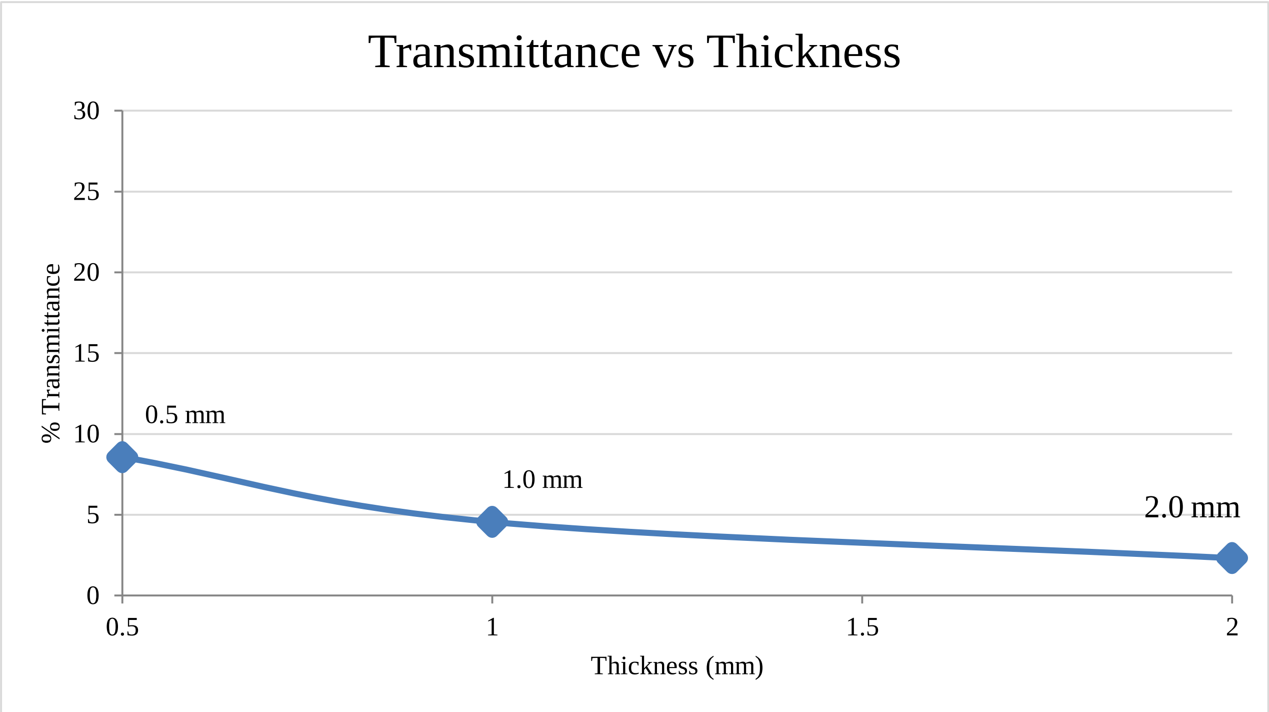

Figure 5: Transmittance as a function of Thickness of Samples with the Same Porosity

Among the thinner samples tested, a relationship between reflectivity and pore size could be observed. Figure 6 shows a linear relationship between pore size and reflectivity. One may note that as the material gets thicker, any effect pore size has on the reflectivity of the material gets overwhelmed by the more powerful influence of thickness. Weiner noted a strong reflectivity dependence on the density of a pressed PTFE powder, with maximum reflectivity occurring in powder having a density of $1 g/cm^3$[11].

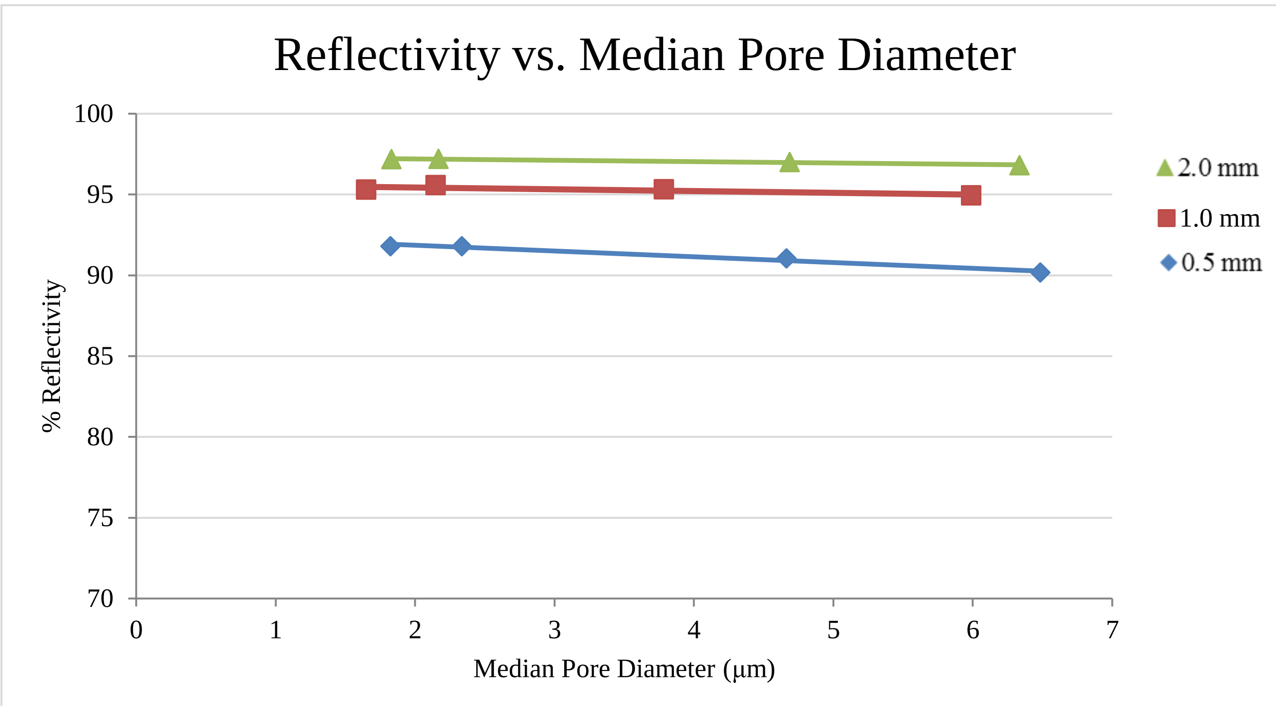

Figure 6: Reflectivity as a function of pore diameter.

Applications

There are some inherent properties of sintered porous PTFE that lend the material to novel, high performance reflectivity applications. Pure PTFE, unlike many other polymers, shows little degradation under UV exposure above 240 nm. As mentioned earlier in this paper, the reflectance in the UV range is not only excellent but also the reflected energy is nearly perfectly Lambertian, i.e. diffuse reflectance. Finally, sintered PTFE is chemically inert and can withstand working temperatures of up to ~260°C.

The diffuse reflectivity of porous PTFE can be leveraged in applications where UV uniformity is important. PTFE is a commonly utilized material for light mixing and light measurement in integrating spheres and photometric equipment. For UV curing of polymers, a porous PTFE reflector can address issues related to lack of uniform UV intensity, as non-uniform UV irradiance results in partially cured adhesive and weaker bond strengths. UV LED applications, such as architectural lighting, water sterilization, or medical disinfection, can also benefit from the highly diffuse reflectance properties of porous PTFE, which acts to convert the narrow directional light source to a wider illuminance.

There are many other UV applications that can utilize the diffuse reflectance of porous PTFE. Water disinfection/sterilization equipment using UV, including portable and consumer devices, require a moderated and uniform intensity of light. Other applications can include medical phototherapy, banknote detection, air purification, lab analytical instruments (e.g. chromatography), tanning, sensing, and drug discovery.

Conclusion

These experiments showed that porous PTFE can have excellent reflective properties of UV radiation in the 250 nm – 400 nm range, with over 97% reflectivity at 2 mm thickness and 2.1 micron median pore size. Increasing the thickness of porous PTFE samples will increase the reflectance as the porous structure will internally reflect and return the UV radiation. The reflectance of porous PTFE is greater than that of solid PTFE, which has a total reflectance in the 250 nm – 500 nm range of 85-95%[12].

The reflectance of porous PTFE sheet is also a function of thickness. The reflectance of porous PTFE sheet at 0.5 mm thickness was 92%. By comparison, the porous PTFE sheet sample at 2 mm thick reflected 97.4% of the UV light. Thinner PTFE samples showed higher UV energy transmitted through the sample than their thicker counterparts. Pore sizes – varying between 2 micron and 7 micron in these tests – did not have a significant effect on the total reflectivity of samples.

Nearly 100% of the reflectance for the porous PTFE sheets tested was diffuse (Lambertian distribution). The diffuse reflectance of pure PTFE makes it a good candidate material for high performance UV reflectivity applications, including photometry, water disinfection, UV curing, and medical, laboratory, or diagnostic applications. Further work may be done to characterize the bidirectional reflectance distribution function (BRDF) and directional hemispherical reflectance (DHR) of these materials.

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