Characterization of the Reflectivity of Various Black Materials

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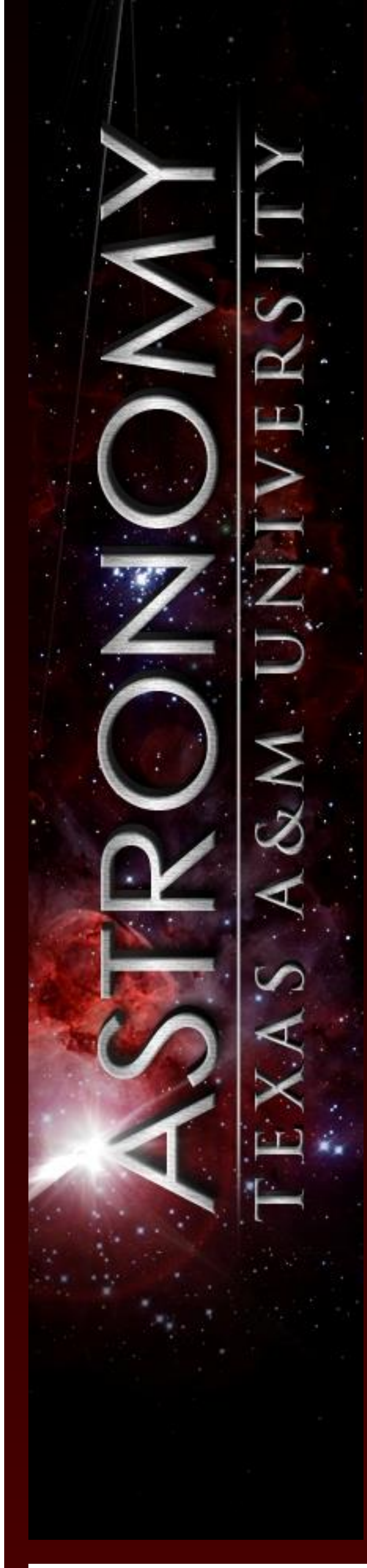

Abstract

We present total and specular reflectance measurements of various materials that are commonly (and uncommonly) used to provide baffling and/or to minimize the effect of stray light in optical systems. More specifically, we investigate the advantage of using certain black surfaces and their role in suppressing stray light on detectors in optical systems. We measure the total reflectance of the samples over a broad wavelength range ($250 < \lambda < 2500$ nm) that is of interest to astronomical instruments in the ultraviolet, visible, and near-infrared regimes. Additionally, we use a helium-neon laser to measure the specular reflectance of the samples at various angles. Finally, we compare these two measurements and derive the specular fraction for each sample.

Introduction

An important consideration in the design and construction of optical and infrared astronomical instruments is the minimization of stray and scattered light within the instrument. Historically, a wide range of materials have been used to minimize unwanted reflections within an instrument, from simple household materials to specialized treatments such as black anodization of aluminum. In recent years, a wide variety of modern sophisticated materials, paints, and coatings have been developed specifically for this purpose. Nearly all of these materials appear "black" to the human eye; this property, however, does not guarantee that the materials function adequately as blackout materials at the wide range of wavelengths studied by astronomical instruments. In this paper we present measurements of the total and specular reflectance of various black materials that may be used to minimize unwanted reflections over a wavelength range relevant to optical and infrared astronomical instrumentation ($250 < \lambda < 2500$ nm).

Materials Tested

We have tested a range of materials that may be used to baffle the optical path and minimize stray light in modern astronomical instruments. The table below provides a list of the specific materials tested.

Sample	Description
A.R.B	Raw 6061 Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
A.M.B	Machined 6061 Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
A.P.B	Polished 6061 Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
A.B.B	Bead-Blasted 6061 Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
A.R.H	Raw 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
A.M.H	Machined 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
A.P.H	Polished 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
A.B.H	Bead-Blasted 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
C.R.B	Raw Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
C.M.B	Machined Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
C.P.B	Polished Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
C.B.B	Bead-Blasted Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
C.R.H	Raw Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
C.M.H	Machined Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
C.P.H	Polished Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
C.B.H	Bead-Blasted Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
I.R.N	Raw Invar (thick), Electroless Nickel Coat (MIL-C-26074)
I.M.N	Machined Invar (thick), Electroless Nickel Coat (MIL-C-26074)
I.P.N	Polished Invar (thick), Electroless Nickel Coat (MIL-C-26074)
I.R.N	Raw Invar (thin), Electroless Nickel Coat (MIL-C-26074)
I.P.N	Polished Invar (thin), Electroless Nickel Coat (MIL-C-26074)
S.R.N	Raw Stainless Steel, Electroless Nickel Coat (MIL-C-26074)
S.M.N	Machined Stainless Steel, Electroless Nickel Coat (MIL-C-26074)
S.P.N	Polished Stainless Steel, Electroless Nickel Coat (MIL-C-26074)
Permanent Marker on Aluminum	6061 Aluminum coated with Sharpie black permanent marker
Weathered Permanent Marker on Aluminum	6061 Aluminum coated with Sharpie black permanent marker left outside from 6 August 2012 to 27 August 2012
Black Masking Tape	Thor Labs T743-2.0
Black Aluminum Foil	Thor Labs BKF12
Blackout Fabric	Thor Labs BK5
Black Foam Board	Black foam board purchased at an arts and craft store.
Black Permanent Marker	Cardboard sample coated in black permanent marker (Sharpie).
Black Dry Erase	Cardboard sample coated in black dry erase marker (Expo).
Black Duct Tape	Cardboard sample covered in black duct tape.
Black Velcro	Cardboard sample covered in adhesive velcro (fuzzy side).
Black Electrical Tape	Cardboard sample covered in standard black electrical tape.
Black Felt	Black felt sample purchased at an arts and craft store.
Black Construction Paper	Typical black construction paper.
Valspar	Spray can Valspar premium enamel, flat and fast drying, for interior/exterior and ideal for wood, metal, and more.
Rustoleum	Spray can Rust-oleum specialty high heat tough protective enamel for grills, wood stoves.
Spraypaint	Generic spray paint for interior/exterior and fast drying.
Acktar Fractal Black	Black oxide optical coating sample from Acktar Advanced Coatings.
Acktar Metal Velvet	Black oxide optical coating sample from Acktar Advanced Coatings.
Rhodes LP Polisher	JH Rhodes polishing material.
Flock 55	Edmund Optics Black Out Material Flock 55
Flock 65	Edmund Optics Black Out Material Flock 65

Total Reflectance Measurements

We used the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer in the Materials Characterization Facility (MCF) at Texas A&M University in order to obtain reflectance profiles for the samples. The U-4100 dual beam spectrophotometer uses two different lamps to cover a wide range of wavelengths. For the far-UV ($\lambda<345$ nm), the U-4100 uses a deuterium lamp; the system uses a tungsten lamp for UV, visible, and near-IR measurements. The layout of the U-4100 includes monochromators, beam splitters, mirrors, focusing lenses, and detectors which can be used to analyze liquid or solid samples. With this system we measured precise reflectance values at each wavelength (in 1 nm steps) for the wavelength range $250 < \lambda < 2500$ nm.

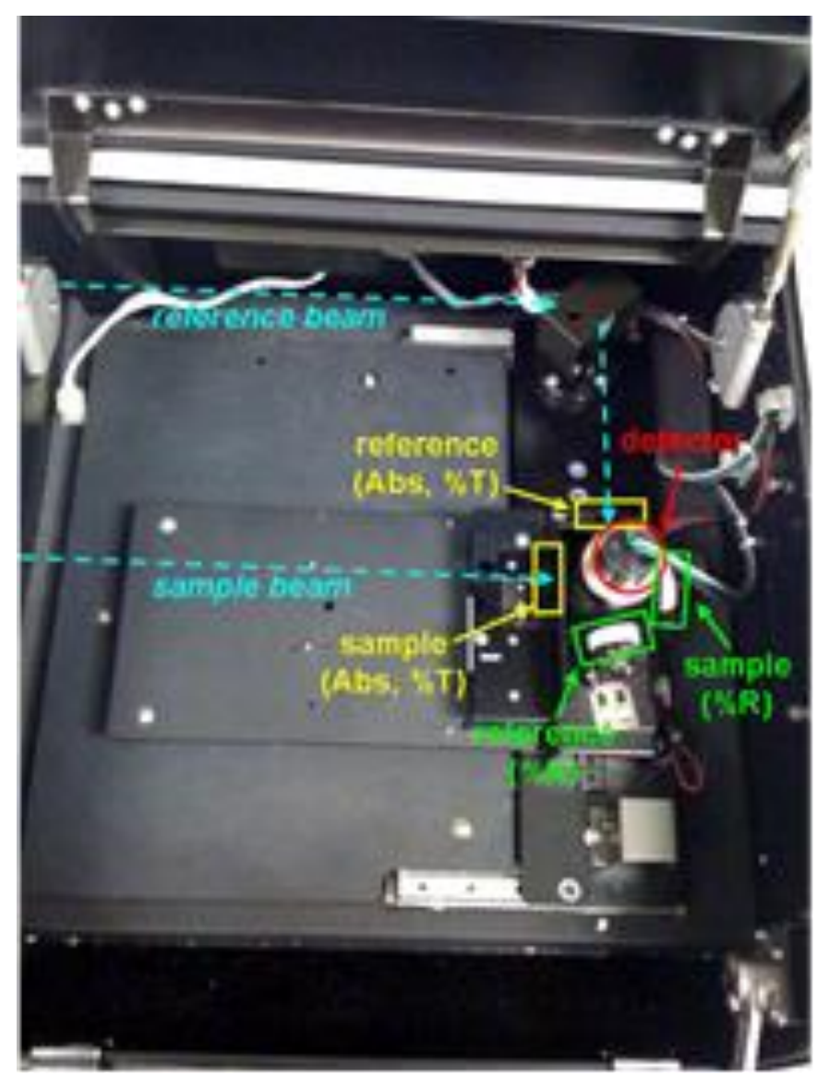

Figure 1. Instrumental setup of the Hitachi U-4100 spectrophotometer.

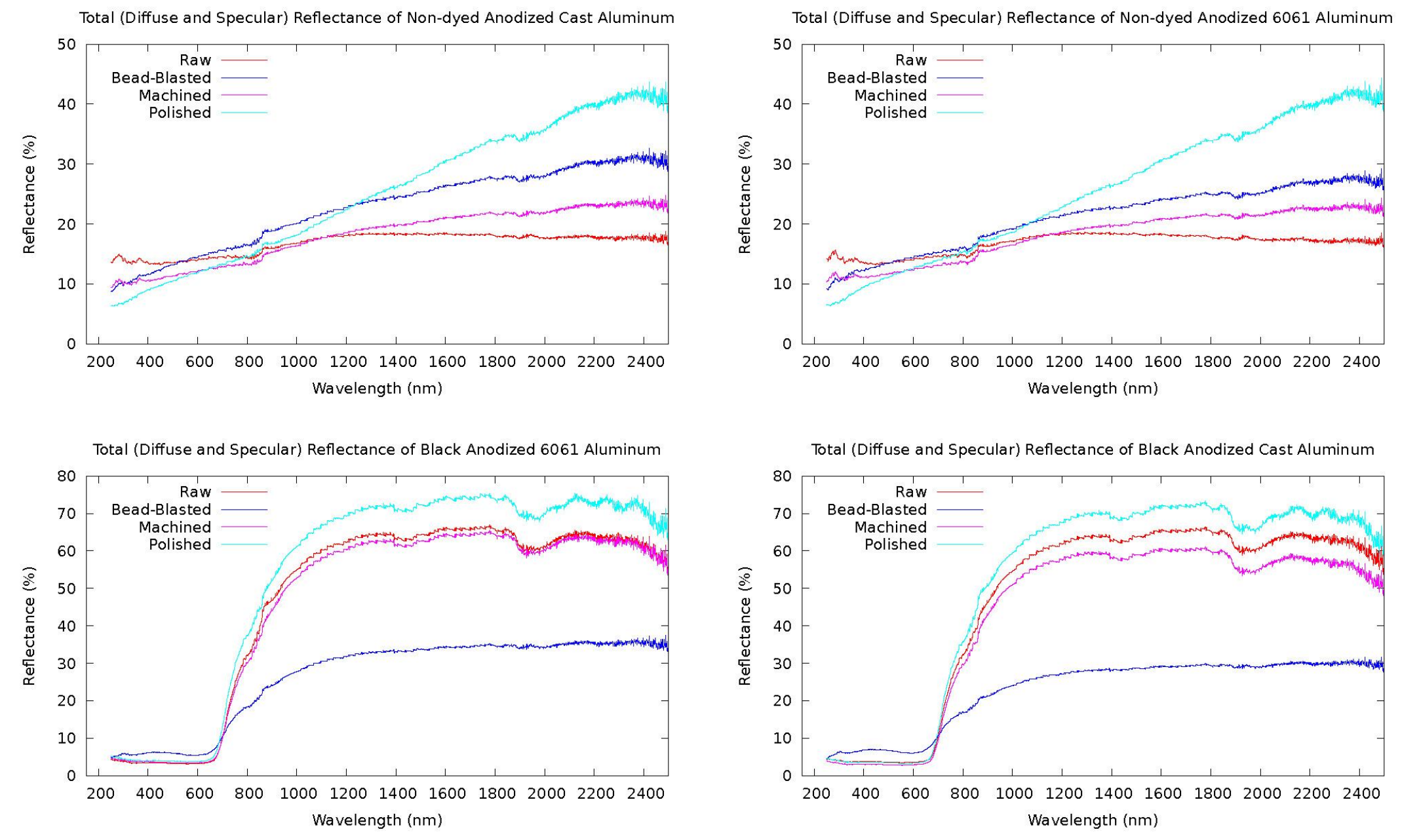

Figure 2. Total reflectance of aluminum samples.

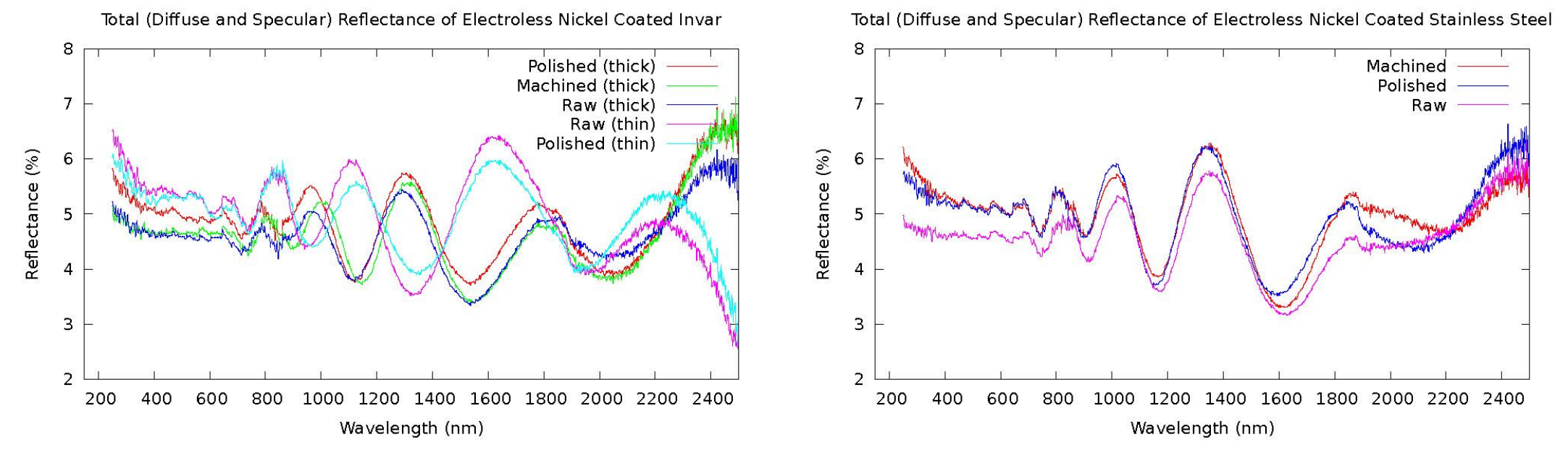

Figure 3. Total reflectance of Invar and stainless steel samples.

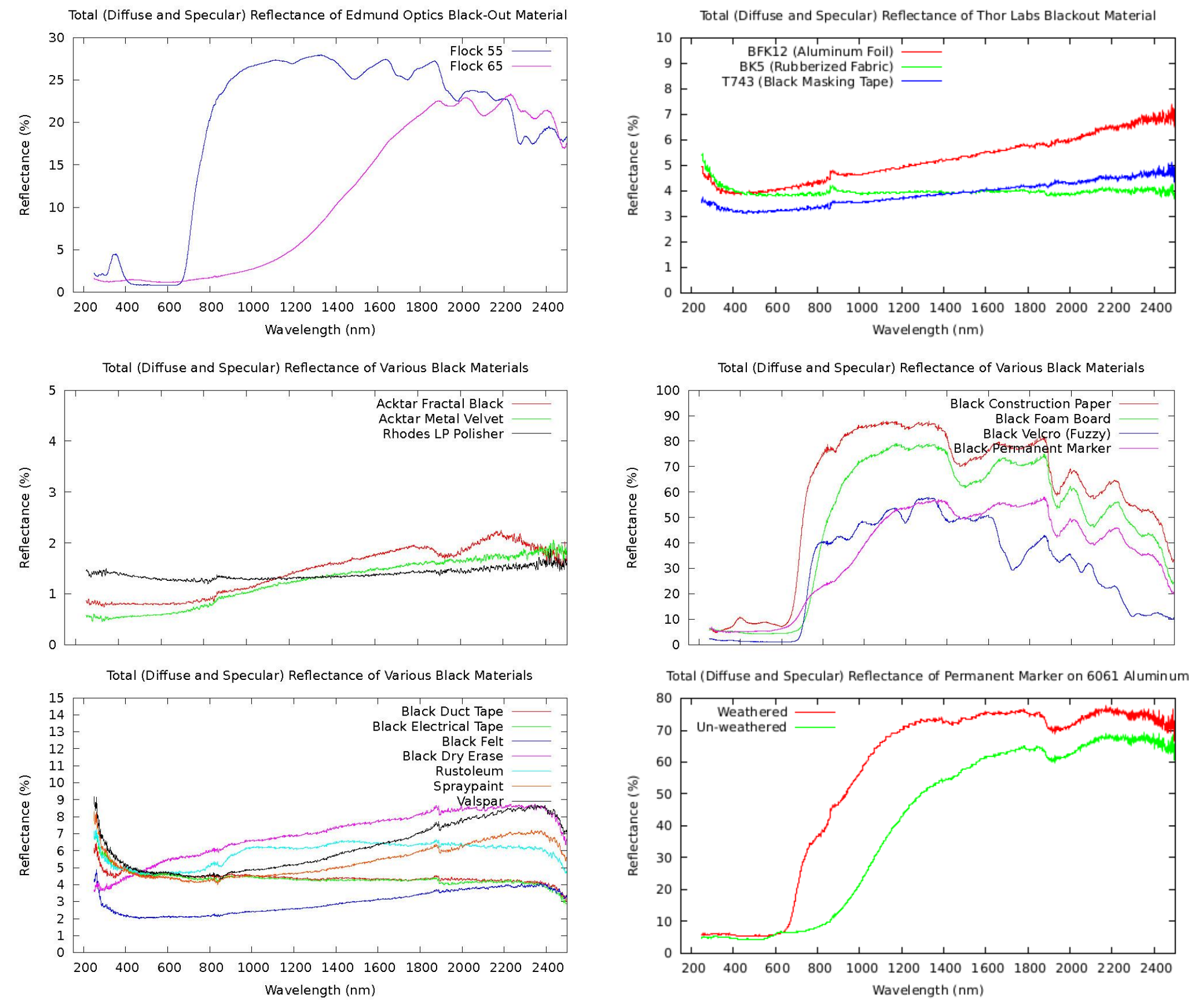

Figure 4. Total reflectance of various commercial and household blackout and baffling materials.

Specular Reflectance Measurements

We also measured the specular reflectance for many of the samples. In this measurement we use a Helium-Neon laser reflected by the surface of each of our samples at 10°, 22°, and 44°. We use a Gentec Photo-Detector (PH100-SiUV; S/N: 181951) to measure the specular intensity at distance of approximately 1 meter from the sample. Figure 5 shows the specular reflectance setup constructed on an optics bench in the Munnerlyn Astronomical Instrumentation Laboratory at Texas A&M University. All measurements were taken in a dark room environment.

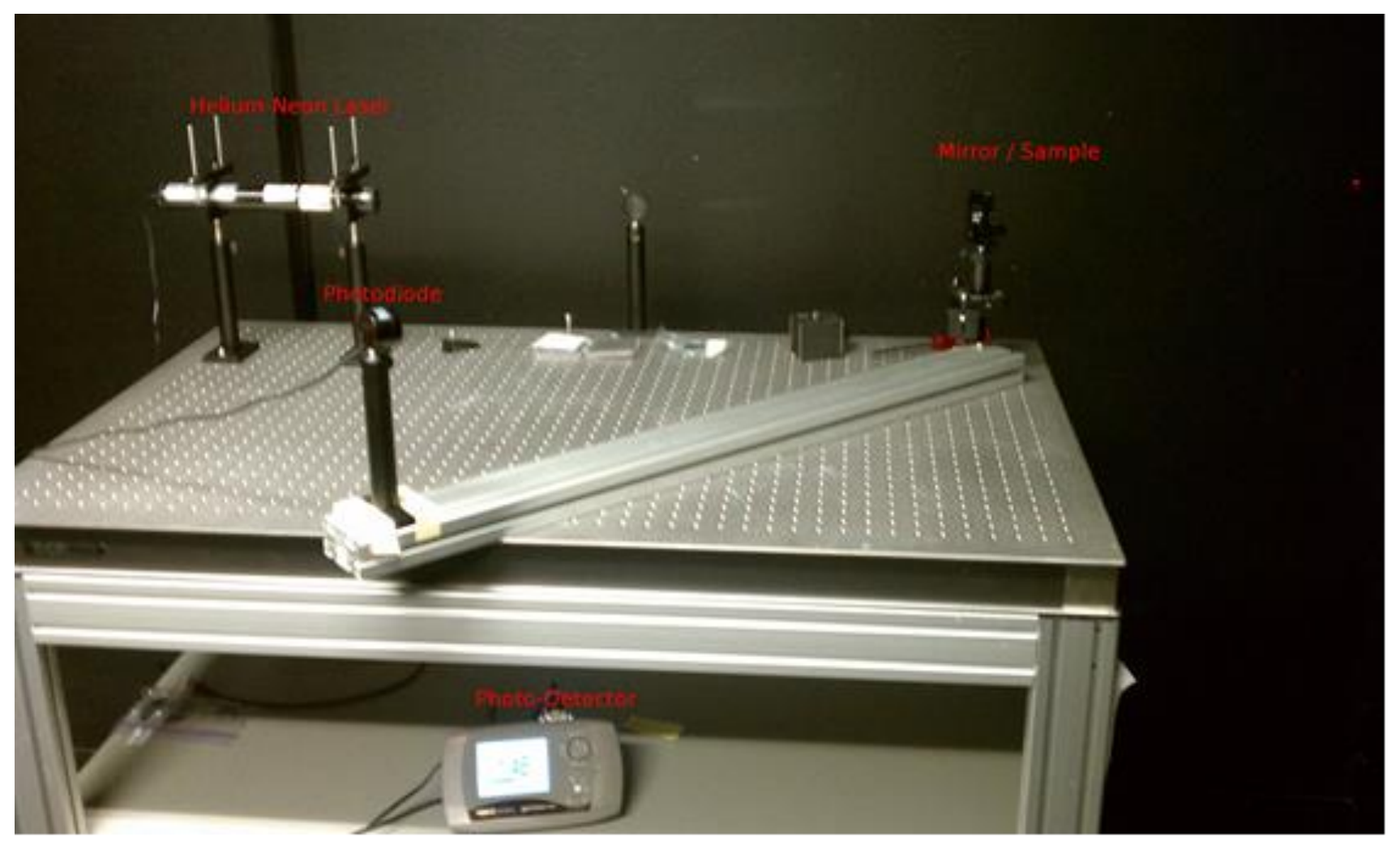

Figure 5. Experimental setup for specular reflectance measurements. The setup consists of a Helium-Neon laser (top-left) which is reflected by the sample (top-right) and sent towards the photodiode detector (middle-left) where an intensity measurement is taken using the Gentec photo-detector readout (bottom-middle). The arm on which the photodiode is mounted is articulated to obtain measurements at each of the three angles. the ratio of the specular to total reflectance of each sample is computed to determine each sample's fraction of specular reflectance.

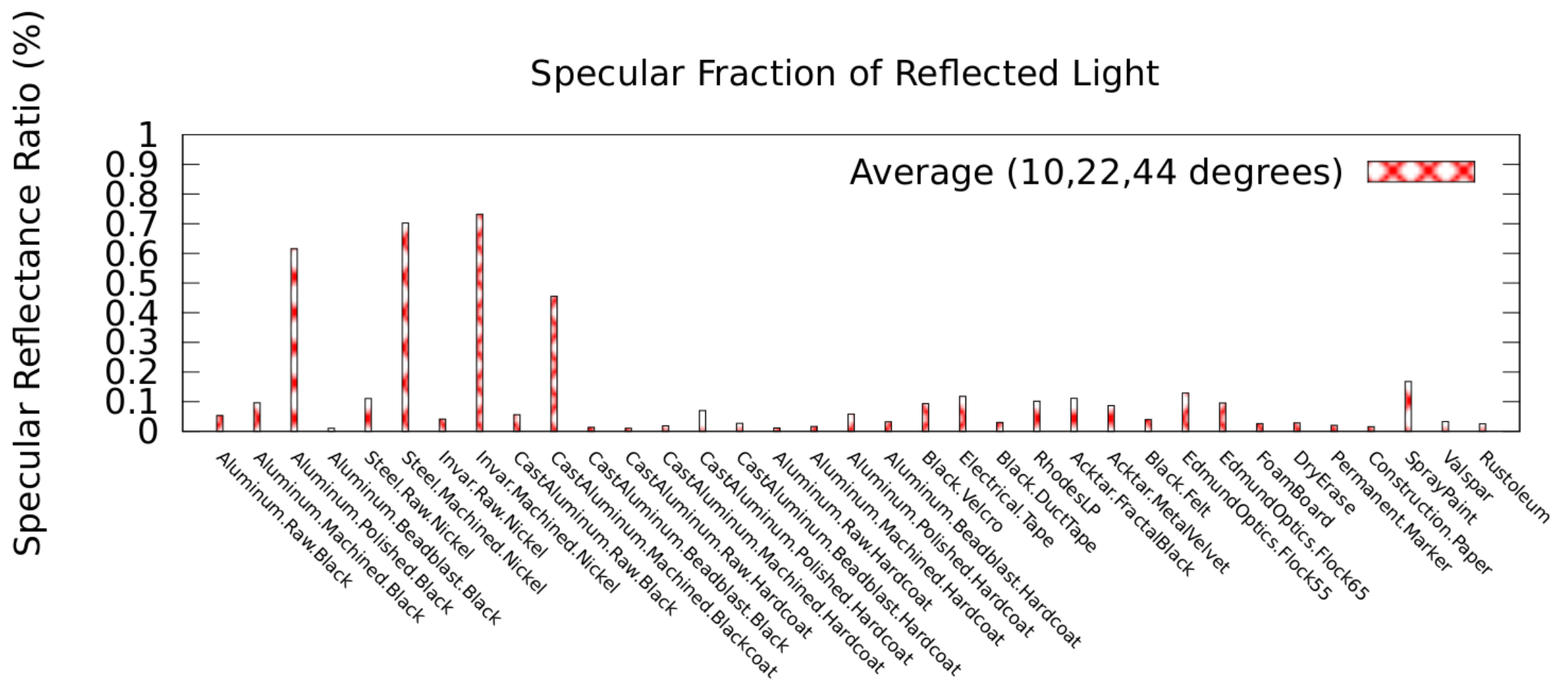

Figure 6. Specular reflectance of a subset of the samples.

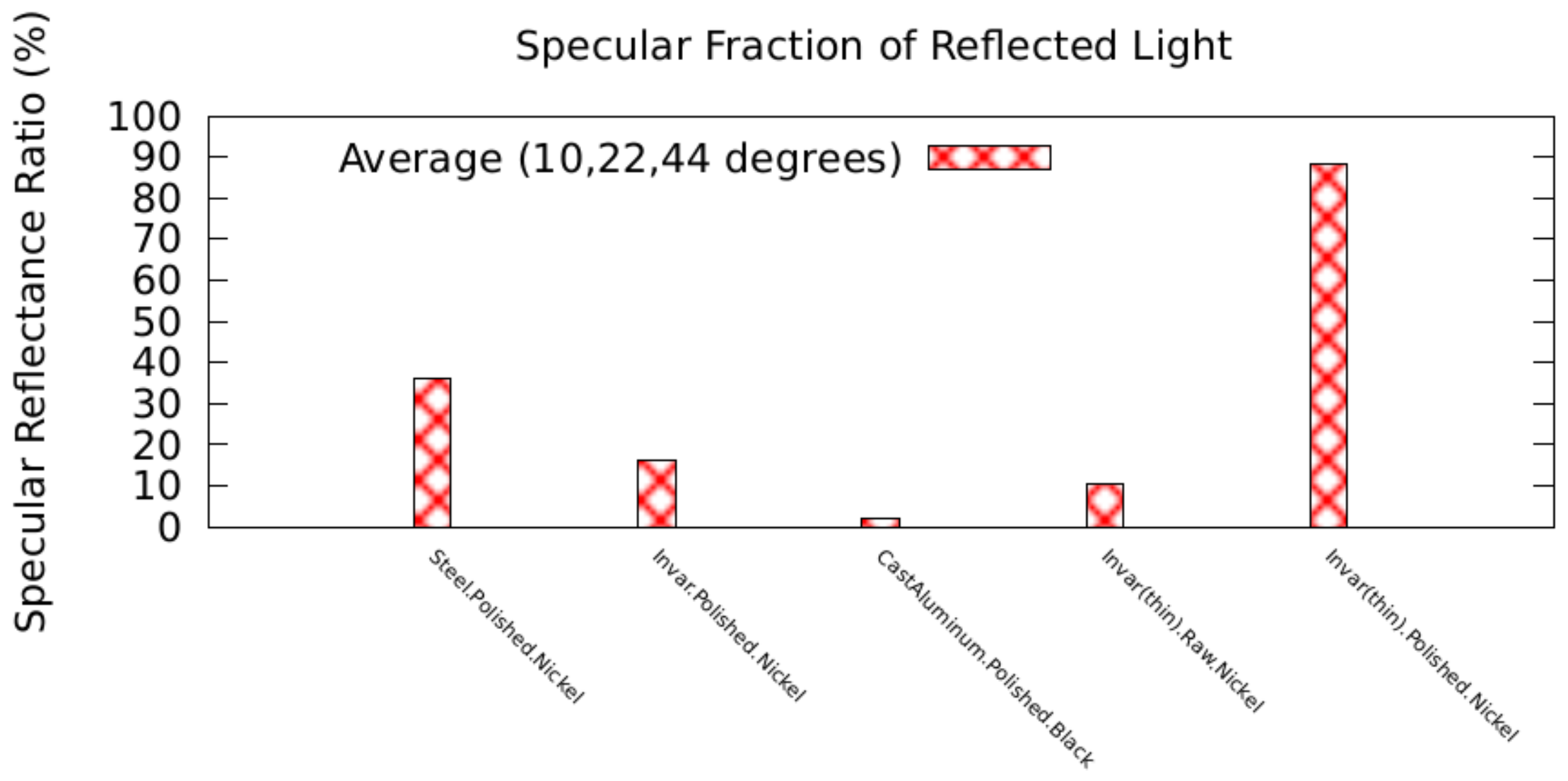

Figure 7. Specular reflectance of a subset of the samples.

Conclusions

We have presented measurements of the amount of total and specular reflectance of various materials that have been or may be used to minimize stray and scattered light within optical and near-infrared astronomical instruments. We have shown some expected, and also some surprising, properties of these black materials. We note that the appearance of blackness or shininess to the human eye is not necessarily a measure of the appropriateness of a material for minimizing scattered light along an optical path. If reflection of stray light by surfaces within an instrument is a significant concern, appropriate blackening of metal and non-metal surfaces within the instrument should be carefully considered.

Texas A&M University Department of Physics and Astronomy is an institutional member of:

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GMT

HETDEX Illuminating the Darkness
Hobby-Eberly Telescope Dark Energy Experiment

LSST Large Synoptic Survey Telescope

DARK ENERGY
SURVEY

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