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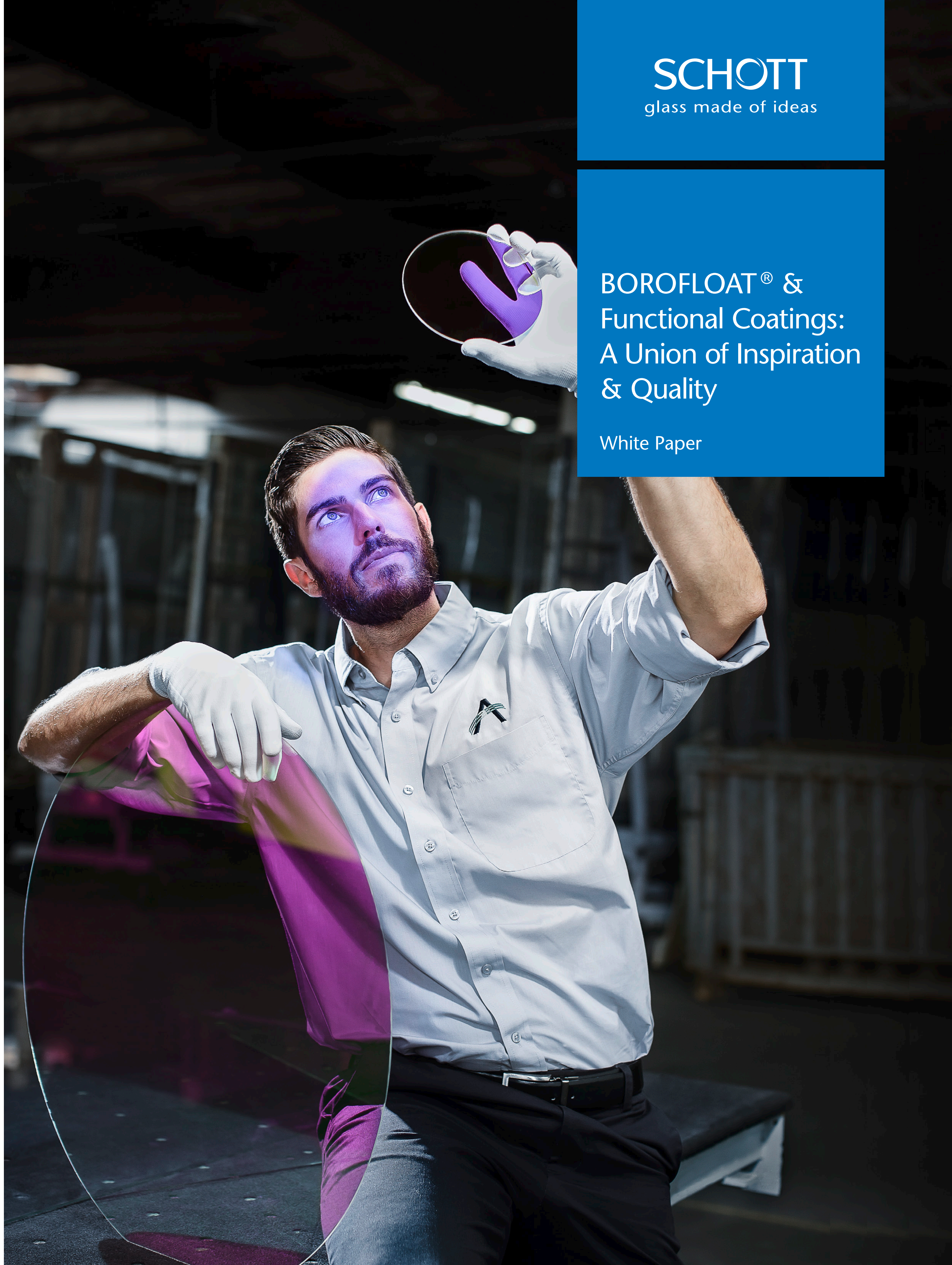
SCHOTT
glass made of ideas

BOROFLOAT® & Functional Coatings: A Union of Inspiration & Quality

White Paper



BOROFLOAT® & Functional Coatings: A Union of Inspiration & Quality

The performance requirements for optical filters and mirrors are highly dependent on the material's ability to reflect, absorb, enhance or modify incoming light. This can be accomplished with bulk optical glass materials or through coatings that are applied to a pristine glass substrate. Coatings usually allow significantly more freedom for customized light management design options which can be developed even further when a flat glass material with outstanding optical, thermal, mechanical and chemical properties is used. BOROFLOAT® borosilicate glass is such a unique substrate and has hence become the material of choice for robust high-temperature resistant dichroic filters, hot and cold mirrors.

1. Introduction

SCHOTT as a highly respected brand in the world of glass is especially well known for its advanced high-quality materials and components. Borosilicate glass was one of Otto Schott's greatest inventions as it stands up to high heat, resists chemical attack and has outstanding optical qualities. The glass, originally used as thermometer glass, labware and lamp cylinders, has evolved into a material with unlimited potential. Whether it be an oven door window, a biochip or a component used in theater spotlights, film projectors or diving robots, few glass types can claim to be as versatile as BOROFLOAT® – the world's first floated borosilicate glass available on the market in pristine quality for over 20 years.

Specialized coating companies have discovered BOROFLOAT® glass as a substrate for advanced coatings capable of performing under the most challenging conditions.

BOROFLOAT® – The sum of its properties is what makes it unique for functional coatings

- Exceptionally high transparency
- Outstanding thermal resistance
- Excellent mechanical strength
- Broad range of sizes and thicknesses

BOROFLOAT® glass is a top performer when it comes to conventional or specialized applications and is often the material of choice, even for price-sensitive projects.

2. BOROFLOAT® – the perfect choice for dichroic filters

The word dichroic derives from the Greek words "di" and "chroma" which stand for "two" and "color" and represents the amazing color-reflecting properties that dichroic materials are known for. Dichroic glass appears to have more than one color at the same time, especially when viewed at different angles and is reminiscent of the rainbow pattern seen when oil floats on water. The principle is similar as dichroic filters are created by coating glass with several ultra-thin layers (15 – 50) of metals or metal oxides that have different reflective indexes. Such layers are usually vacuum-deposited and less than 1 micrometer thin. The coating itself doesn't have its own inherent color, but rather bends light to reflect colors exactly as a prism or the oil film that creates a rainbow effect. The many combinations of coated layers allow for endless possibilities that inspire engineers and artists alike.

NASA originally developed dichroic glass in 1950's to protect sensitive spacecraft instruments from harmful cosmic radiation. However, the ability to reflect and absorb only certain wavelength ranges quickly opened new opportunities and today dichroic filters are used in architectural and entertainment lighting, fiber optic color wheels, light correction, electronic devices, heat and UV control applications, underwater lighting, medical photonics and many other optical applications.

Dichroic filters, also called inference filters, reflect unwanted light instead of absorbing the energy and are hence often used in high intensity light sources or light engines. Optical properties (perfect visible light transmittance)

along with the temperature resistance of the substrate determine the efficiency and maximum operation temperature of the filter product. Dyed plastics or commercial glass types have limited thermal resistance and plastic color gels tend to age and break down if exposed to high energy light sources. BOROFLOAT® glass however has excellent thermal resistance and low UV radiation damage (low susceptibility towards solarization), withstands thermal gradients and combines superior optical clarity with mirror-like surface quality. Due to its fully linked glass microstructure with a relatively low amount of non-bridging oxygen, BOROFLOAT® glass shows a low degradation behavior during high intensity radiation exposure.

It is therefore not surprising that it quickly became a substrate of choice for dichroic filters and color correction filters throughout the world. Dichroic filters made of BOROFLOAT® glass exhibit significantly better color filter characteristics (for instance steep UV cut-off performance, higher level of visible transmittance), higher laser and X-ray damage threshold and longer lifetimes than other flat glass substrates under challenging user conditions.

The thermal properties of BOROFLOAT® glass (uncoated substrate) are shown aside. Maximum thermal resistance of coated dichroic filters varies depending on the filter supplier but can reach up to 287 °C/550 °F.

2.1 Thermal properties

Maximum operating temperatures	
Maximum Operating Temperature	
For short-term usage (< 10 h)	500 ° C
For long-term usage (≥ 10 h)	450 ° C

Resistance to Thermal Gradients (RTG) and Resistance to Thermal Shock (RTS) must be considered when determining max. operation temperatures.

Resistance to Thermal Gradients (RTG)			
Glass Thickness	Tempering	RTG	
		T_{change}*	$T_{heat\text{-}up}$*
3.8 mm	No	123 K	136 K
6.5 mm	No	119 K	132 K
11 mm	No	52 K	173 K
18 mm	No	31 K	188 K
6 mm	Thermal	> 300 K	

Edges ground or polished

* T_{change}: sudden temperature change
$T_{heat\text{-}up}$: continuous heat-up

Panels measuring 25 x 25 cm² (10 x 10 inches²) are heated in the center of the panel to a defined temperature; the edges are maintained at room temperature. The temperature is increased within one minute to a level that initiates breakage of the test panel. The temperature is controlled via pyrometer. The RTG value is the difference in temperature between the hot center of the panel and the cool panel edge, at which breakage occurs in less than or equal to 5 % of the samples. In order to simulate damage that can occur in practical use, the samples are abraded with 220 grid sandpaper before testing.

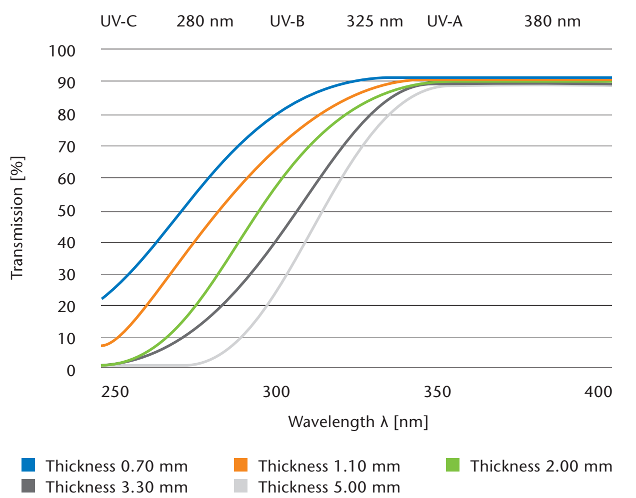
Resistance to Thermal Shock (RTS)	
Glass Thickness	RTS (5 %-Fraktil)
≤ 3.8 mm	175 K
5.0 – 5.5 mm	160 K
6.5 mm	155 K
11 mm	142 K
18 mm	144 K
25 mm	128 K

Panels measuring 20 x 20 cm² (8 x 8 inches) are heated in an oven with circulating air and afterwards doused in the center with 50 ml of cold water (68 degree F). The temperature is controlled via pyrometer. The RTS value is the difference in temperature between the hot panel and the cold water, at which breakage occurs in less than or equal to 5 % of the samples. In order to simulate damage that can occur in practical use, the samples are abraded with 220 grid sandpaper before testing.

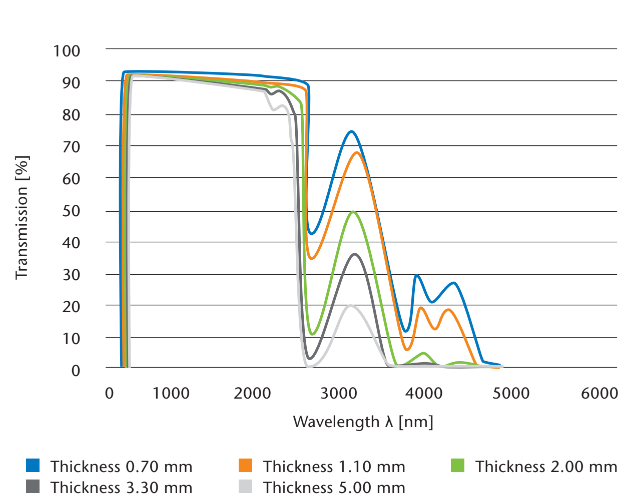
2.2 Optical Properties

The graph below shows the spectral transmittance range for selected BOROFLOAT® glass thicknesses and some basic optical characteristics. Additional information is available on request.

Transmission in UV range



Transmission

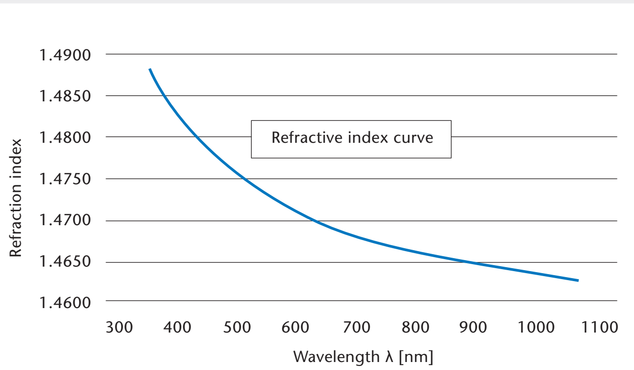


Optical index of refraction

Wavelength λ (nm)	Refraction index n
435.8	1.48015
479.9	1.47676 ($n_{F'}$)
546.1	1.47311(n_e)
589.3	1.47133
643.8	1.46953 ($n_{C'}$)
656.3	1.46916

Mean reference values, not guaranteed values.

Dispersion



Optical data

Abbe number ($\nu_e = (n_e - 1) / (n_{F'} - n_{C'})$)	65.41
Refraction index (n_d ($\lambda_{587.6\ nm}$))	1.47140
Dispersion ($n_F - n_C$)	71.4 x 10^{-4}
Stress-optical coefficient (K)	4.0 x 10^{-6} mm² N^{-1}

Average reference values, not guaranteed values.

Dichroic filters are also often referred to as beam splitters which are used to split light into two or more separate beams in optical systems. Beam splitters are essential for many applications such as interferometers, tele-prompters, vision systems, electronic displays, instrumentation, POP displays and flight simulators.

3. Hot & Cold Mirrors

Hot & Cold mirrors have the fascinating ability to either reflect infrared light (heat) and transmit visible light (hot mirrors) or – the opposite – transmit infrared light and reflect visible light (cold mirrors).

Both mirror types require substrates that have excellent clarity, high light transmittance and – given that operating temperatures are easily above 300 °C – are able to withstand high temperatures. BOROFLOAT® glass complies with such requirements and has been used as substrate material in many applications.

Similar to dichroic filters, vacuum deposited or sputtered multilayer coatings are applied to the substrate to create hot mirrors that either harness the reflected wavelengths or remove them from an application. This is especially important in optical systems where excessive heat can damage components or affect the characteristics of a light source. Hot mirrors are for instance used in halogen/HID lamps to increase filament temperatures resulting in less power consumption, increased efficiency, longer life-times and reduced cost. Typical hot mirrors reflect > 90 % of the IR wavelengths (750 nm – 1250 nm) while transmitting > 90 % of the visible light (425 nm – 675 nm), making them ideal as mirrors in LCD displays, (fiber optic) lighting, medical & dental applications, heat/light separation, aerospace, as IR filters in CCD cameras and cinemas, and as desktop projectors to prevent system damage. Various angles of incidence are available.

A cold mirror is a high efficiency heat/light separation device that is used to remove heat from light that hits a surface while still providing high levels of illumination. It transmits infrared light but reflects non-infrared light spectral bands, helping to eliminate heat that is unwanted or that can damage equipment. They are used as cool light sources in medical lighting (surgical and dental lights), dielectric mirrors in sensor technology, laser diodes, scanners and bar code readers, projectors and photocopiers.

4. Outlook

Dichroic filters and hot and cold mirrors are among many other optical applications for which BOROFLOAT® glass has been used. High transparency in the UV range down to 300 nm, greater than 92 % light transmittance capabilities in the Visible and Near IR wavelength range, outstanding colorless visual appearance, low auto-fluorescence and low solarization tendency are specific property requirements in many optical fields. A variety of optical glass materials comply with such requirements. However, the added thermal and chemical resistance, along with its high energy radiation exposure capabilities, make BOROFLOAT® glass an optical substrate unmatched in versatility and flexibility for many different applications that require more than just excellent optical characteristics.

The sum of its properties is what makes it unique!