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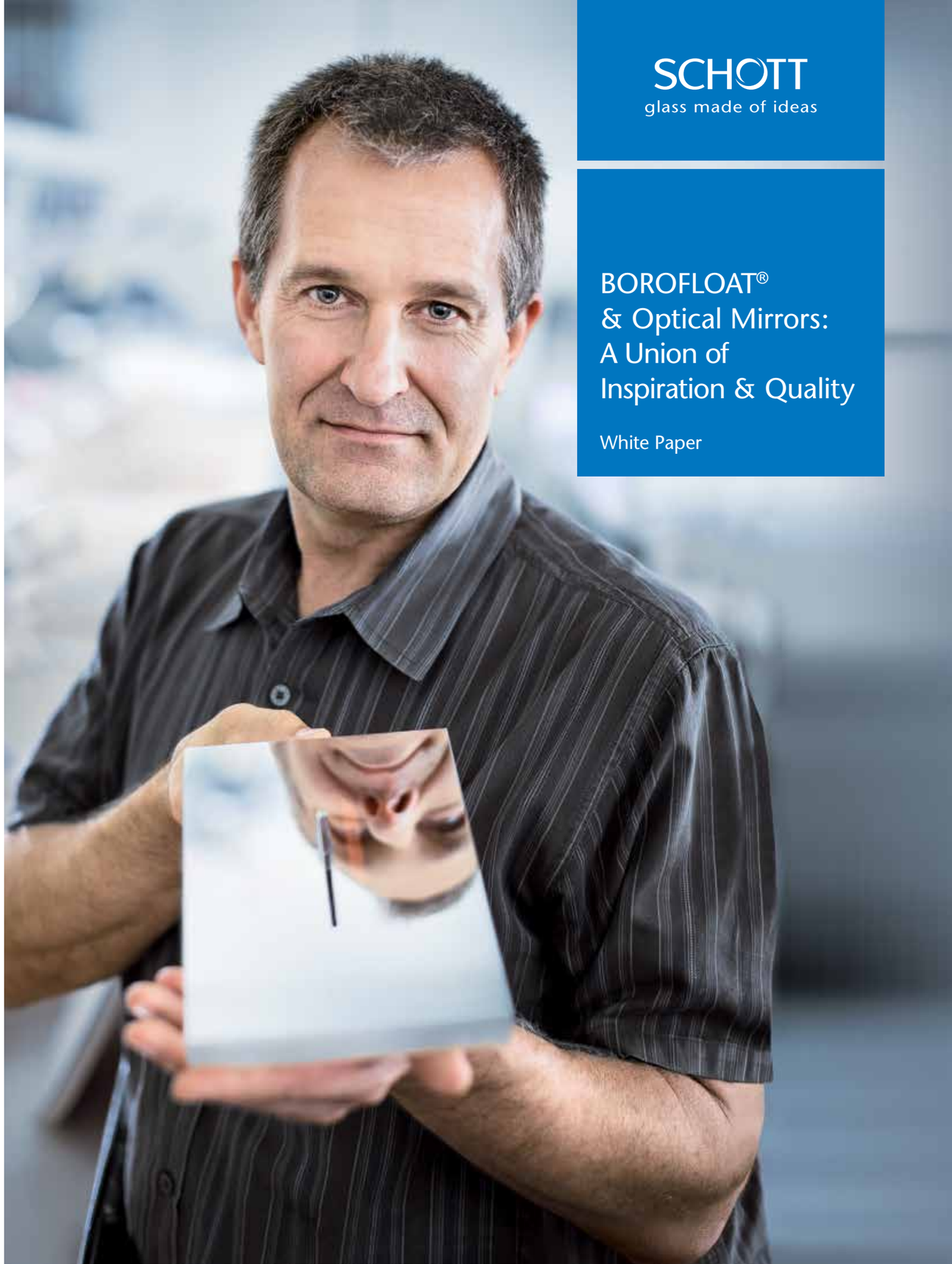


SCHOTT
glass made of ideas

BOROFLOAT® & Optical Mirrors: A Union of Inspiration & Quality

White Paper

BOROFLOAT® & Optical Mirrors: A Union of Inspiration & Quality

The performance requirements for optical mirrors are extremely rigorous as slight deviations can have significant impacts on the outcome of specific performance. Thermal stability is a must if mirrors are used in environments subjected to temperature changes. Excellent surface quality combined with exceptionally high transmission and reasonable cost are other attributes that engineers consider when specifying their material of choice. BOROFLOAT® glass meets such demanding requirements and has been used for sophisticated optics around the globe.

1. Introduction

SCHOTT is widely renowned in the glass world for its advanced high quality materials and components. Specialty glasses and glass ceramics for highly sophisticated and technically demanding optical applications are the bedrock of our long and proud history. For more than 130 years SCHOTT has been able to meet and exceed the requirements of such advanced optical applications by developing specialty materials that offer unique, multifunctional performance characteristics. The impressive combination of excellent optical properties with low thermal expansion and outstanding thermal resistance is exemplified by BOROFLOAT® - the world's first floated borosilicate glass. Following its inception in 1993, BOROFLOAT® kick started the beginning of a new era in borosilicate glass usage by introducing – for the first time - oversized, extra-flat and homogeneous sheet sizes with clarity comparable to optical glasses. Since then it has been used in a broad variety of applications and has even enabled us to better understand the universe.

2. BOROFLOAT® glass utilized to research our universe

Einstein's Theory of General Relativity has transformed theoretical physics and astronomy for more than a century and „reigned as the explanation for how gravity works" [1]. But recently scientists have begun to question whether it is "possible that gravity weakens on the largest scales" [1] of our universe. An international group of scientists are collaborating on a major project, called HETDEX [2], to explore something that makes up 3/4 of our universe - Dark Energy, „a mysterious force that is causing the universe to expand faster as it ages" [3]. Astronomers had always anticipated that the universe's expansion following the Big Bang 13.7 billion years ago would slow down but recent research shows a trend towards expansion. HETDEX will help find answers and uses the giant Hobby Eberly Telescope (HET), for which SCHOTT provided the gigantic 11 meter ZERODUR® mirror, in combination with a Visible Integral Field Replicate Unit Spectrograph (VIRUS). The 150 spectrograph mirrors used in VIRUS are made from BOROFLOAT® specialty glass.

VIRUS consists of an array of new instruments that analyze light emitted from more than one million galaxies that are more than 9 to 11 billion light years away. HETDEX will produce a 3 dimensional map of parts of our universe using 150 spectrographs mounted on the telescope. Such spectrographs will measure the light from distant galaxies and break it down into individual wavelengths used to reveal an object's chemical composition, temperature and how fast it is moving. Using redshift analysis, scientists are able to determine if and how fast an object moves away or towards us. HETDEX will finally allow astronomers „to measure how fast the universe was expanding at different times in its history. Changes in the expansion rate will reveal the role of dark energy at different epochs „[3].

Precision Glass & Optics, based in Santa Ana, CA, fabricates the optical mirrors required in such spectrographs using BOROFLOAT®. Aside from extremely stringent optical requirements, these mirrors also require superior surface quality and need to resist extreme environmental conditions. According to Dan Bukaty, owner of PG&O, BOROFLOAT® glass was „a great choice because of the low thermal expansion characteristics, excellent optical properties and low cost when compared to other optical materials such as fused silica."

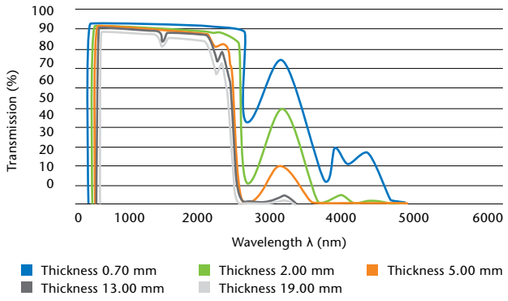
3. Optical properties

BOROFLOAT®´s exceptionally high transparency makes it a key material of choice for optical applications in research and industry. Its unique light transmission over a wide spectrum offers customers a vast wealth of new possibilities.

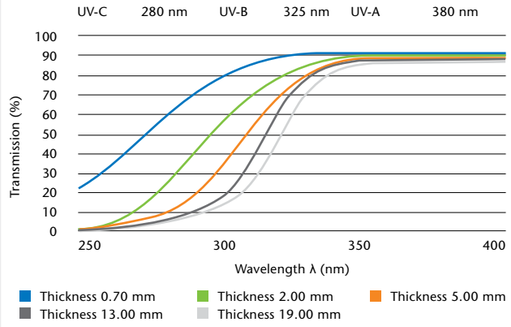
Specific light transmittance values are thickness dependent and significantly influenced by Fe_2O_3 impurity levels.

BOROFLOAT® specialty glass uses only the purest raw materials resulting in extremely low (~90 ppm) iron impurity levels and hence exceptionally high transmission values. In fact BOROFLOAT® is the industrial glass with the lowest level of iron impurity of all float glass materials in the market.

Transmission

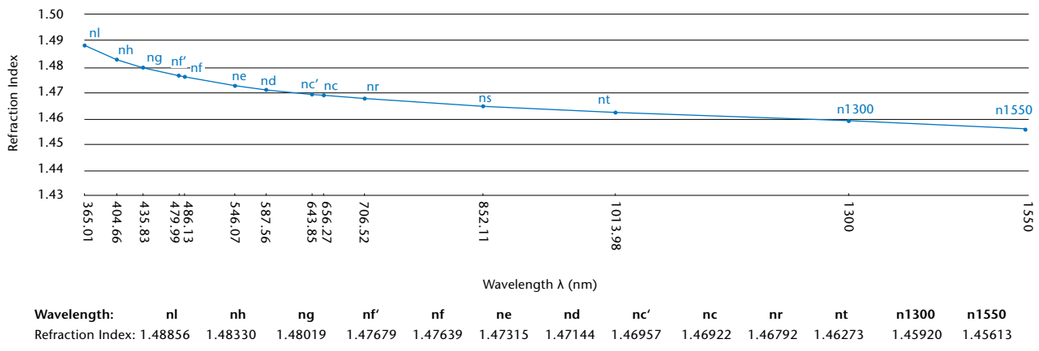


Transmission in UV range



Another noteworthy property of BOROFLOAT® is its low refractive index.

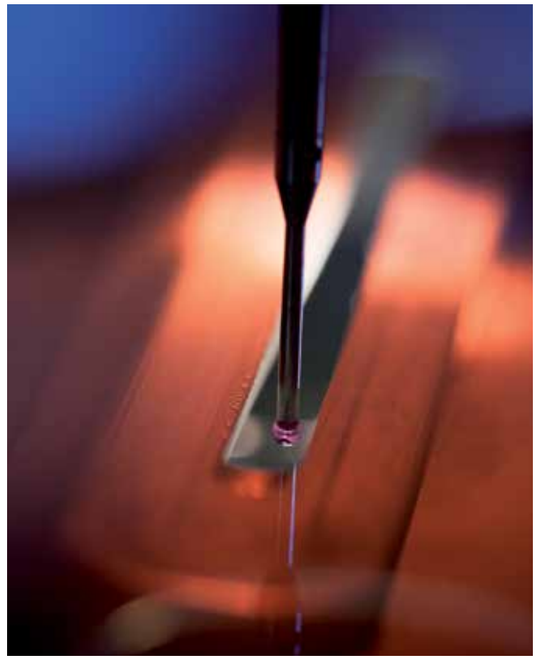
Refraction Index



Wavelength:	nl	nh	ng	nf'	nf	ne	nd	nc'	nc	nr	nt	n1300	n1550
Refraction Index:	1.48856	1.48330	1.48019	1.47679	1.47639	1.47315	1.47144	1.46957	1.46922	1.46792	1.46273	1.45920	1.45613

4. Thermal Properties

The glass composition of BOROFLOAT® specialty glass is not only tailored towards excellent optical properties. It is also designed to provide a very low thermal expansion and high chemical durability. The element boron plays a significant role in delivering such special properties as it determines how strong the bonds are within the glass network.

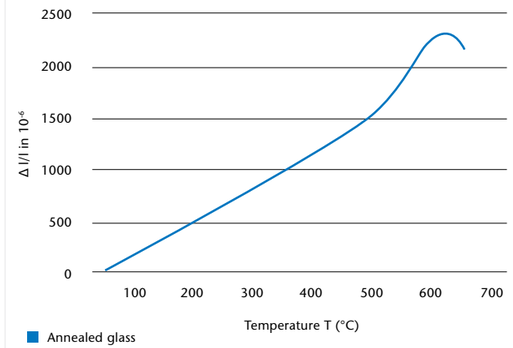


Thermal properties

Coefficient of	
Linear Thermal Expansion (C.T.E.) $\alpha_{(20-300\,°C)}$	$3.25 \times 10^{-6}\ K^{-1}$ *
Specific heat capacity $c_{p\ (20-100\,°C)}$	0.83 kJ/(kg·K)
Thermal conductivity $\lambda_{(90\,°C)}$	1.2 W/(m·K)

* According to ISO 7991.

Thermal expansion



The combination of its properties is what makes BOROFLOAT® the material of choice for the fascinating HETDEX project and many other advanced optical applications.

5. Outlook

It is the unique sum of its properties that defines the success of our specialty float glass. Over the years BOROFLOAT® has made possible a multitude of innovative products across a broad spectrum of applications in research and industry. Its timeless versatility makes it one of the most attractive specialty glasses available. And there really is no end in sight as BOROFLOAT® continues to support customers in in their relentless pursuit for technological breakthroughs.

BOROFLOAT® specialty glass - used to look beyond galaxies.

4. Literature
[1] „What is Dark Energy?“, Hobby-Eberly Telescope Dark Energy Experiment, Hetdex.or
[2] HETDEX is a collaboration of The University of Texas at Austin, Pennsylvania State University, Texas A&M University, Universitäts-Sternwarte Munich, Leibniz Institute for Astrophysics (AIP), Max-Planck-Institut für Extraterrestrische Physik, Institut für Astrophysik Göttingen, and University of Oxford.
[3] HETDEX: Leading the Revolution, Hetdex.org/hetdex