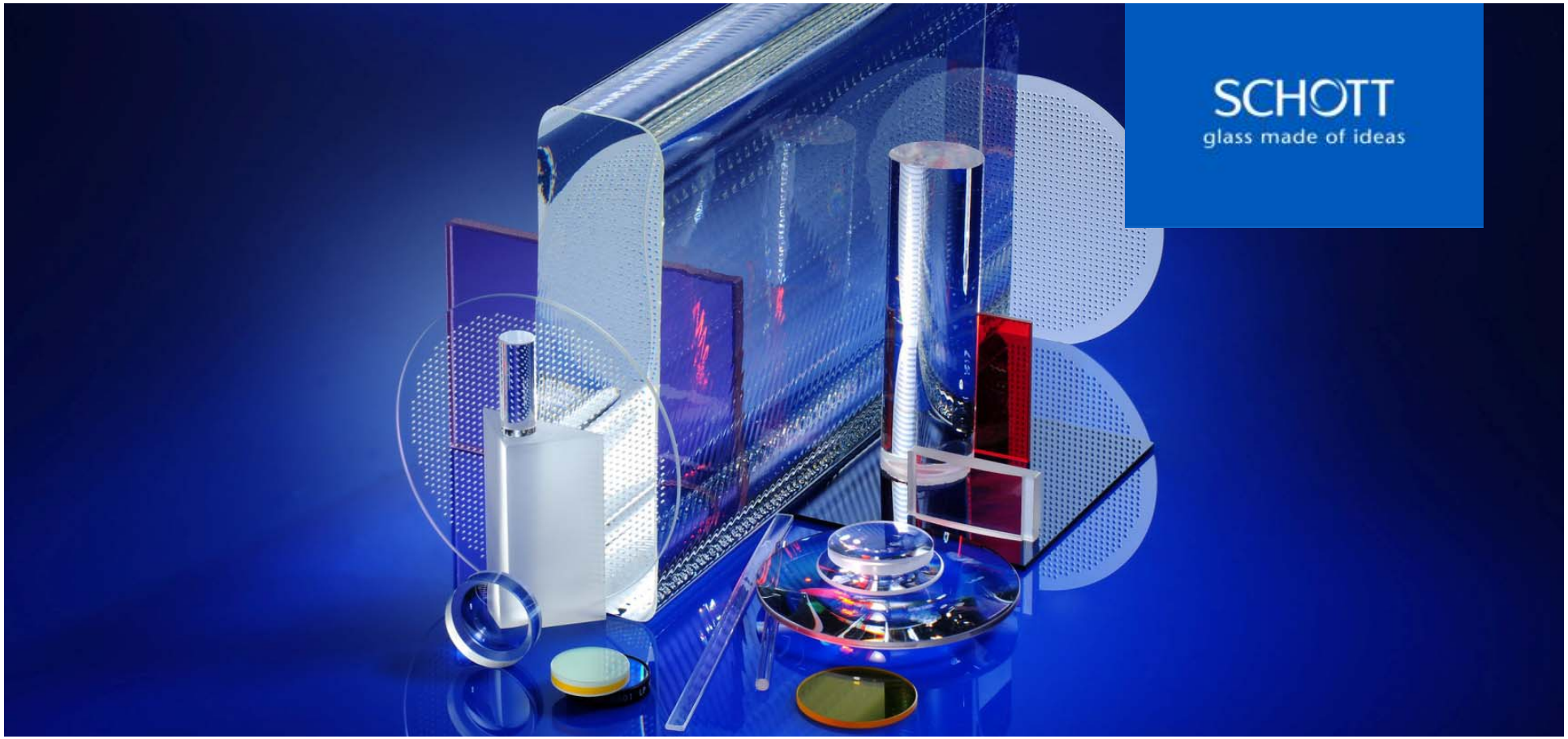


Update on optical materials

Ralf Jedamzik, SCHOTT AG

Optical Materials Tour

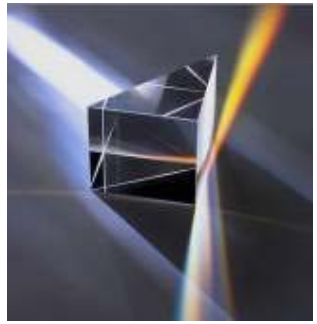
- Optical glass
- Filter glass
- IR materials
- Laser glass
- Ultra thin glasses

Optical glass has well defined, reproducible and homogeneous properties:

- High light transmission
  Transmittance
- Precise light deflection
  Index of refraction, dispersion
- High uniformity in light deflection
  Optical homogeneity
  Stress birefringence
- High material homogeneity
  Bubbles, inclusions, haze
  Crystallization: clarity
- Sufficient mechanical and chemical resistance
  Grinding and polishing behaviour
  Environmental influences
- Availability of a sufficient number of ***glass types*** with different indices of refraction and dispersions matching each other in application

All Properties must be:

- Well defined
- Measureable
- Reproducible
- Constant in minimum piece size and lot size
- Availability of glass types for longer time spans



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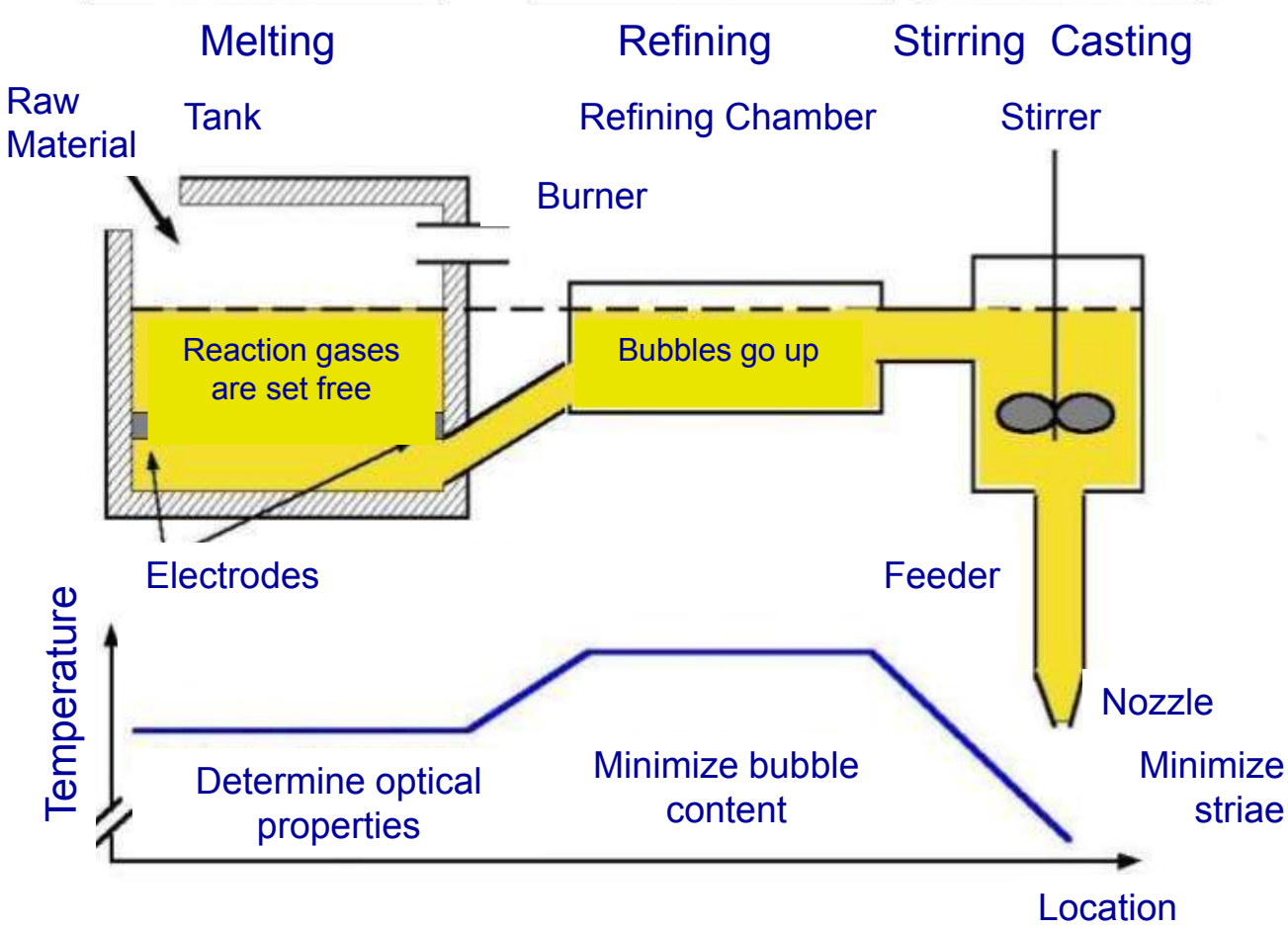
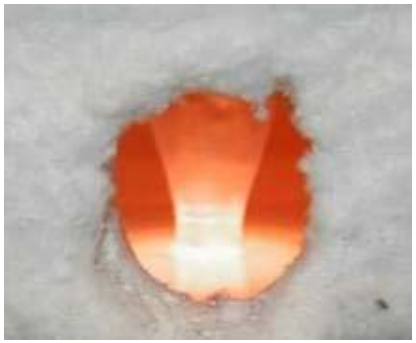
Tank melting – the modern way of optical glass production





Material properties develop in time

Problem:
Putting material together with equal properties to form delivery lots

Advantage:
Much lower costs

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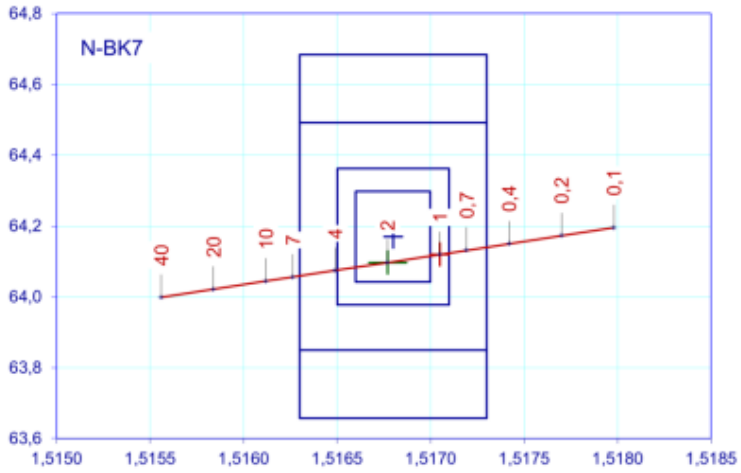
Chemistry alone is not sufficient to define an optical glass type - the annealing state is important also

An optical glass type is not only defined by its chemical composition, but also by its annealing state i.e. the cooling rate the glass has seen during its last temper process

SCHOTT N-BK7®	Index of Refraction	Abbe Number	Anneal. rate K/h
	1,51587	64,09	20
Catalog	1,51680	64,17	2
	1,51773	64,25	0,2



The refractive index change of almost +/- 0,001 is comparatively small but in optical systems very important. It might lead to complete loss of function like focusing.

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Annealing lehr and fine annealing: Strip production

- Endless glass strip travels through the annealing lehr within 6 –10 hours
- Slow cooling down reduces stress within the glass
- Additional fine annealing adjusts the optical position

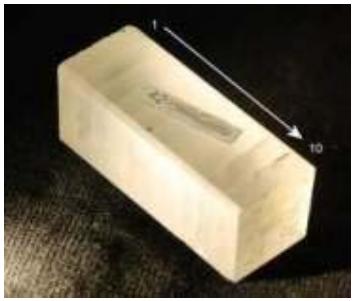
Efficient and accurate **standard** refractive index measurement: *V-block-method*

Accuracy according catalog :

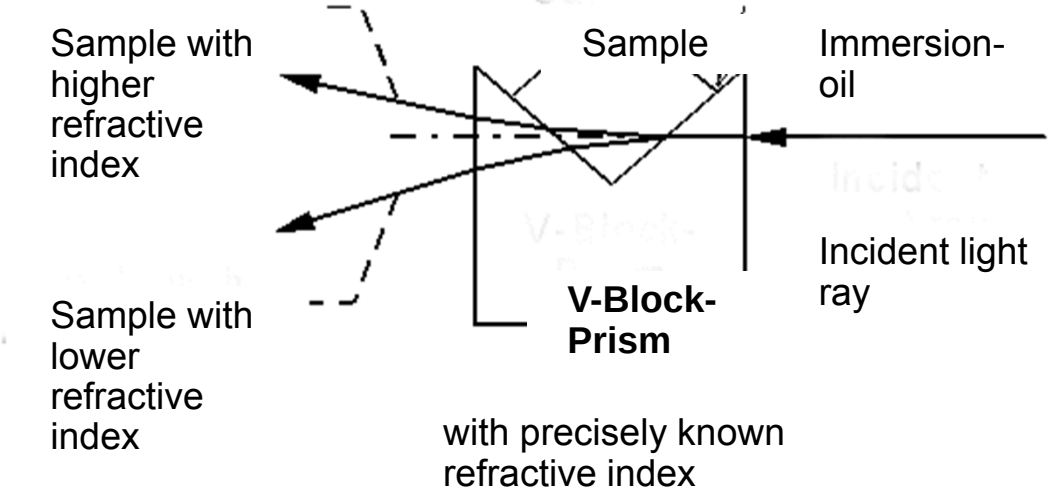
n_d: ± 2-3 x 10^{-5} (99,7%, 3σ)
$n_{F'}$-$n_{C'}$: ± 1-2 x 10^{-5} (99,7%, 3σ)

wavelength:
(i, h), g, F', F, e, d, C', C, (r, t)

Fast, cost effective and very accurate measurement method



Set of v-block samples cemented to one block



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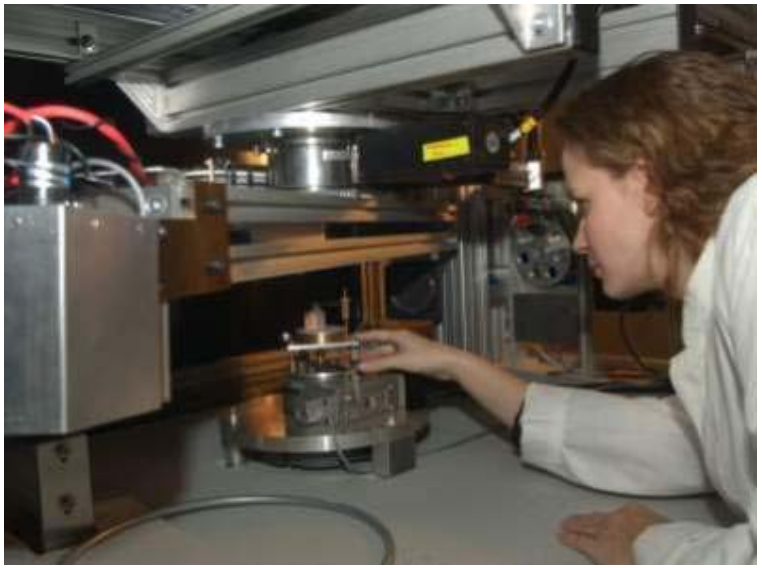
High end refractive index measurement:
UV-IR Spectrometer URIS

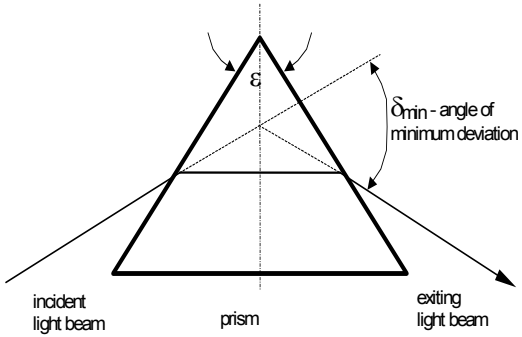
Wavelength range:
0.185 up to 2.325 µm

Accuracy ($\pm$ 3 σ):

Refractive index	$\pm$ 4	$\times 10^{-6}$
Dispersion $n_{F'}$-$n_{C'}$ ($n_F - n_C$)	$\pm$ 2	$\times 10^{-6}$

Temperature: (22 $\pm$ 0.1)°C, 18 - 28°C
Sample size: 35 x 35 x 25 mm





$$n = \frac{\sin\left(\frac{\delta_{min} + \varepsilon}{2}\right)}{\sin\frac{\varepsilon}{2}}$$

U **ltraviolet to infrared**
R **efractive**
I **ndex Measurement**
S **ystem**

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Modern production control enables tightest n_d/v_d tolerances for selected glass types: Step 0.5

- Step 0.5 is the tightest refractive indes tolerance available on the market
- The maximum allowed deviation from the nominal values are
  - ± 0,0001 for the refractive index n_d
  - ± 0,1 % for the Abbe number v_d
- Especially suited for high precision lenses in industrial applications
- Only available for selected glass types:
  - SCHOTT N-BK7® and N-BK7HT,
  - N-KZFS2, N-KZFS4 (HT), N-KZFS5, N-KZFS8, N-KZFS11
  - N-LAK9, N-LASF44, SF2, SF57HTUltra, N-SF5, N-SK2
  - N-PK51, N-FK51A, N-FK5, N-PSK53A
- Further glass types are available on request.
- Only fine annealed as cut blanks
- All measurements utillizing the V-block with enhanced accuracy with referencing

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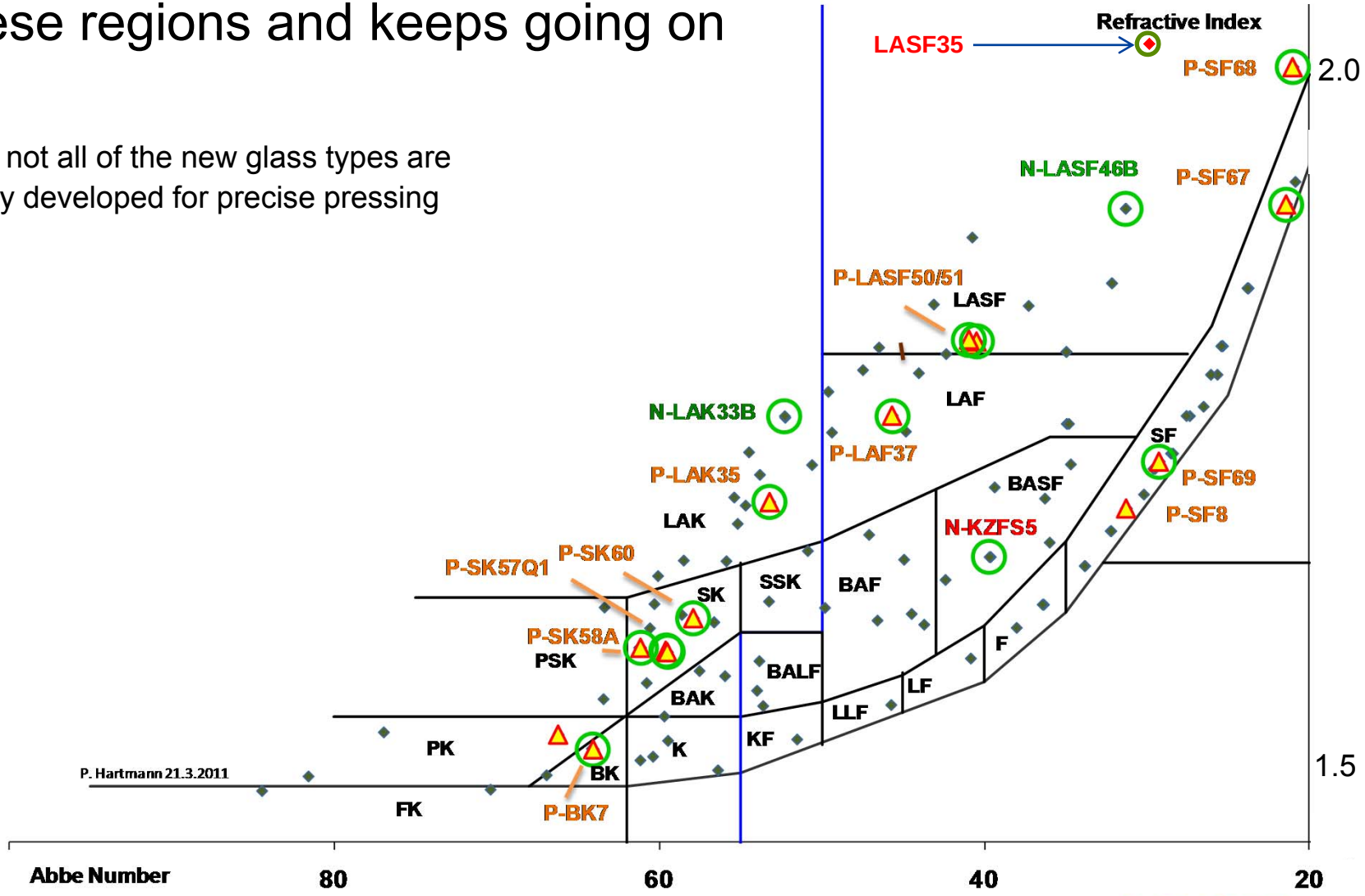
Since 2009 SCHOTT introduced 16 new glass types mostly in these regions and keeps going on

Most but not all of the new glass types are especially developed for precise pressing



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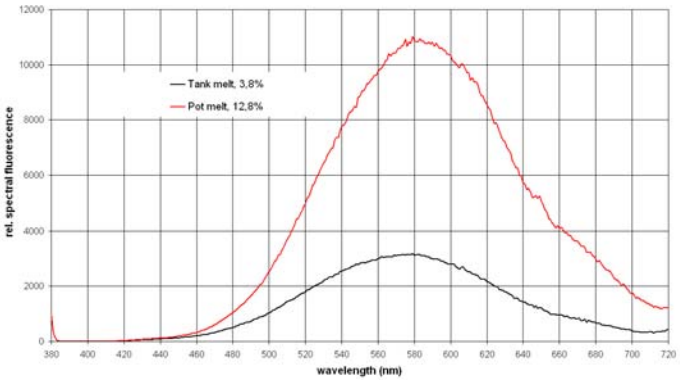
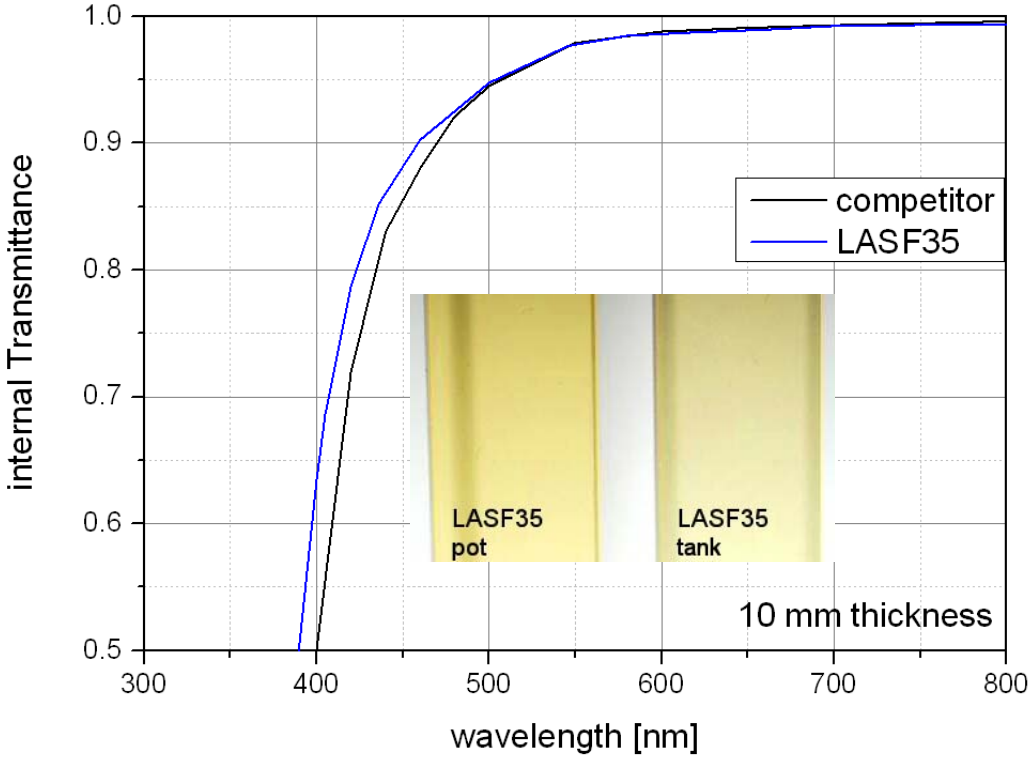
LASF35: Ultra high refractive index glass with excellent internal transmittance

Unique optical position:
n_d=2.02204, v_d=29.06

High transmittance, improved internal quality and fluorescence
due to modern tank production





Now available as preferred glass !

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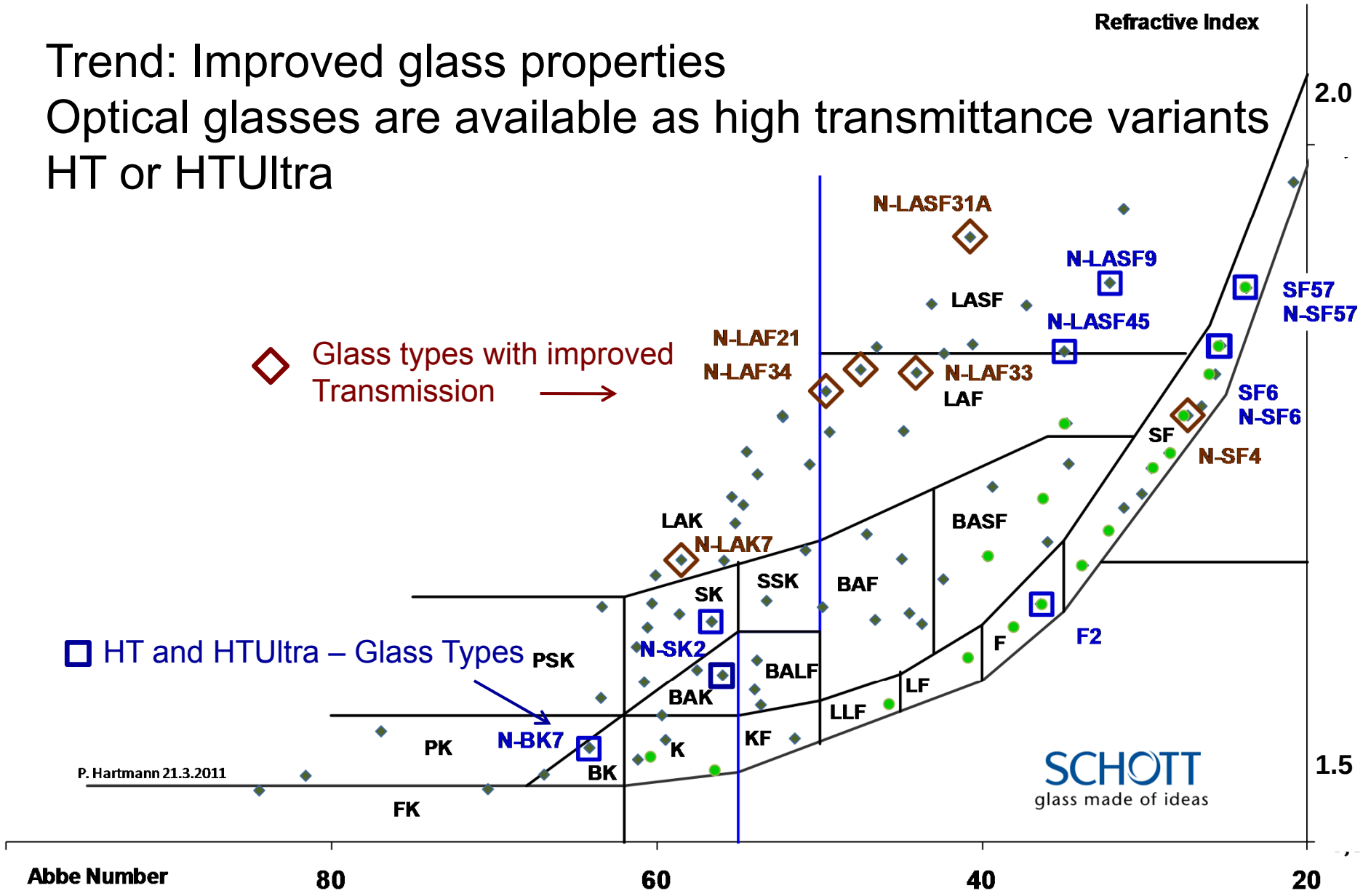
Trend: Improved glass properties
Optical glasses are available as high transmittance variants HT or HTUltra



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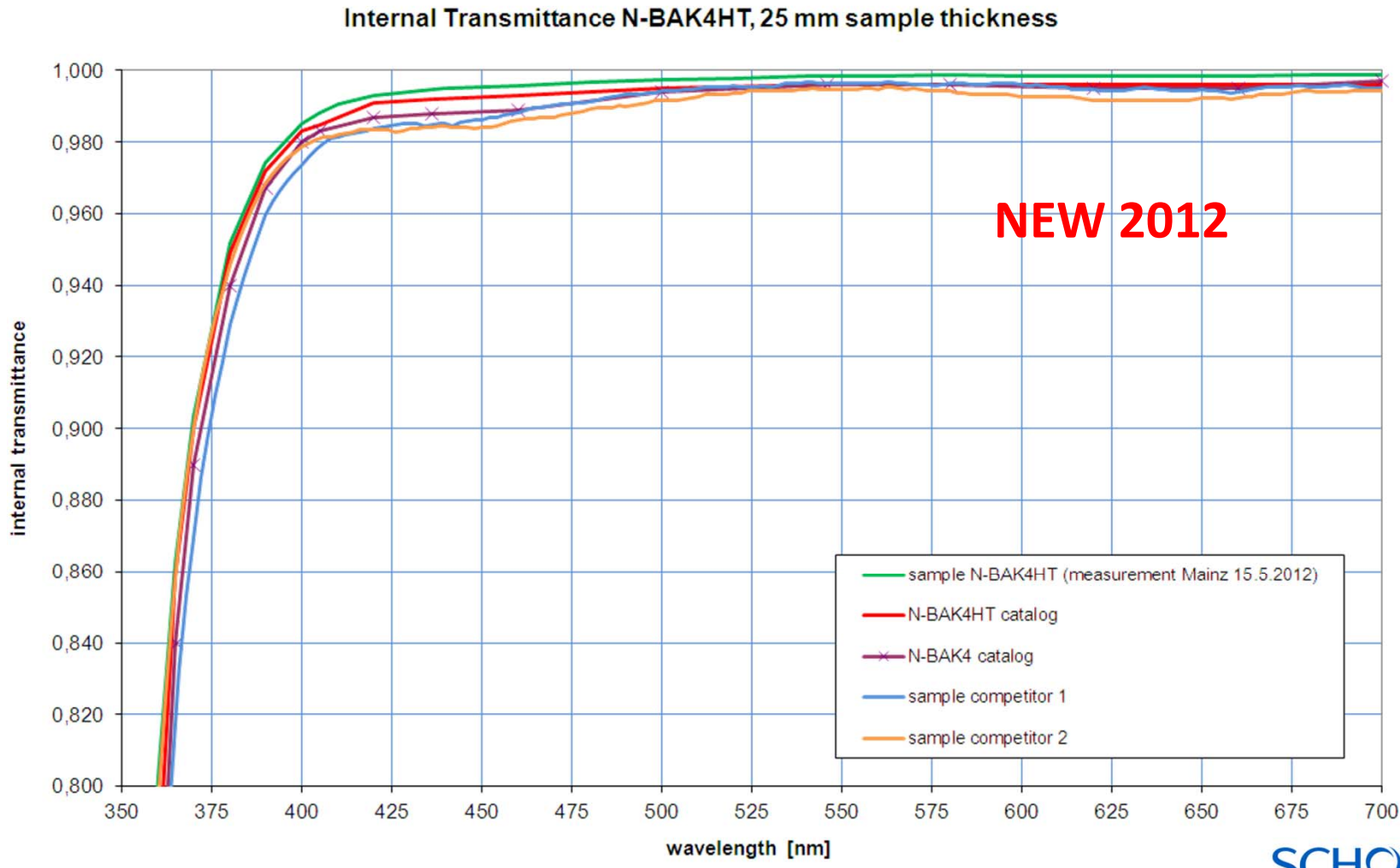
High Transmittance Prism glasses N-BK7HT, N-SK2HT and N-BAK4HT prism glasses:

τ_i ↑



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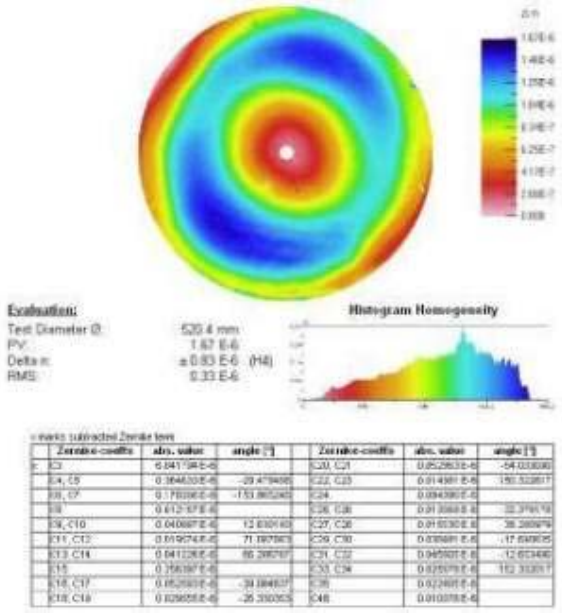
Modern melting technologies and state of the art interferometry enable highest refractive index homogeneity grades*

500 mm and 300 mm high accuracy interferometer

Homogeneity class	Maximum variation of refractive index	Applicability, deliverability
H 1	$40 \cdot 10^{-6}$	For individual cut blanks
H 2	$10 \cdot 10^{-6}$	For individual cut blanks
H 3	$4 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions
H 4	$2 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions, not for all glass types
H 5	$1 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions, not for all glass types



Detailed analysis of homogeneity (Zernicke) possible.

*depending on glass type and dimensions

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High homogeneity glasses available from stock
(as “cut blank”, H4 on 90% of diameter)

Glass type	Max. Dimension [mm]	Homogeneity
SCHOTT N-BK7®*	Ø 600 x 180	H4
	Ø 360 x 100	H4
F2*	Ø 290 x 100	H4
N-FK5	Ø 240 x 50	H4
LLF1	Ø 220 x 45	H4
LF5	Ø 220 x 45	H4
N-FK51A	Ø 200 x 40	H4
N-LAK22	Ø 200 x 50	H4
SF5	Ø 215 x 60	H4
N-KZFS11	Ø 170 x 40	H4

* also in two directions available

New Pocket Catalog 2014

- New refractive index step 0.5 für selected glasses
- High homogeneity glasses up to H4 from stock
- i-Linien glasses
- Simplified bubble quality
- Striae free in 3 directions
- LaSF35 now preferred glass

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Optical glasses almost bubble-free, even in the standard grade

SCHOTT Advanced Optics brings **premium quality** to a **standard level**

- No difference between B0 and B1 anymore.
- All glasses fulfill standard quality!
- New standard grade is equivalent with the old B0 grade.
- All former glasses with grade B1 now fulfill the new standard (former B0).

Old bubble classes

Bubble class	B0	B0 VB	B0 EVB	B1	B1 VB	B1 EVB
Max. crosssection mm² per 100 ccm	0.03	0.01	0.006	0.1	0.03	0.02
Max. quantity per 100 ccm	10	4	2	30	10	4
Max. all. diam.						
50	0.10	0.10	0.10	0.15	0.15	0.10
100	0.15	0.15	0.10	0.20	0.15	0.10
200	0.20	0.15	0.10	0.30	0.20	0.10
300	0.25	0.20	0.10	0.40	0.25	0.10
500	0.40			0.60		
800	0.55			0.80		

Valid for bubbles > 0.03 mm dia.!!!

New bubble quality comprise only three grades

Bubble quality	Standard	VB	EVB
Max. crosssection mm² per 100 ccm	0.03	0.02	0.006
Max. quantity per 100 ccm	10	4	2

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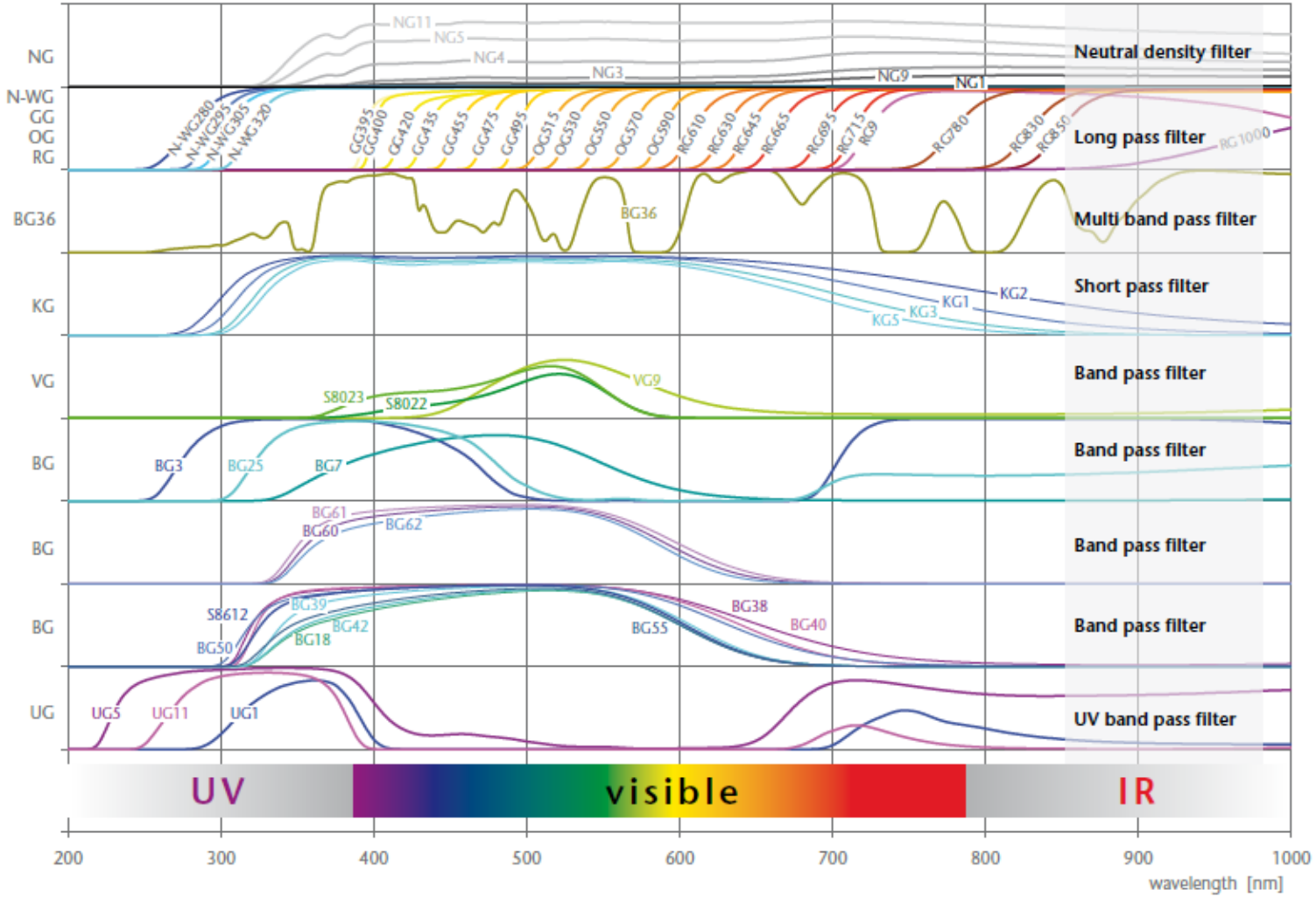
Optical filter glass portfolio cover a broad range of applications



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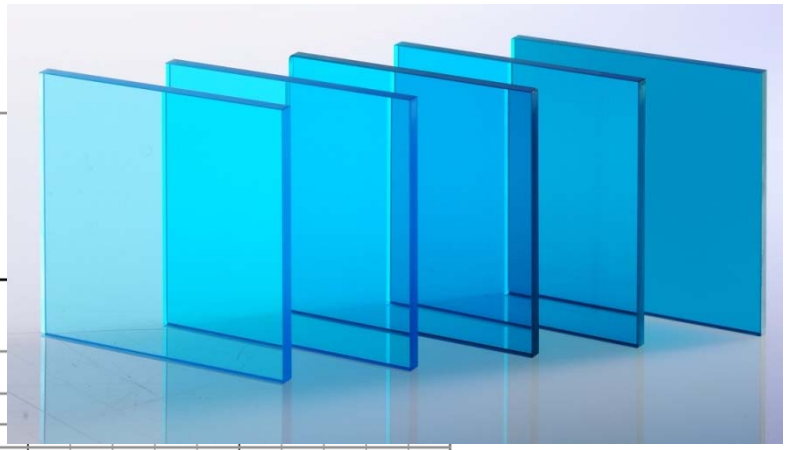
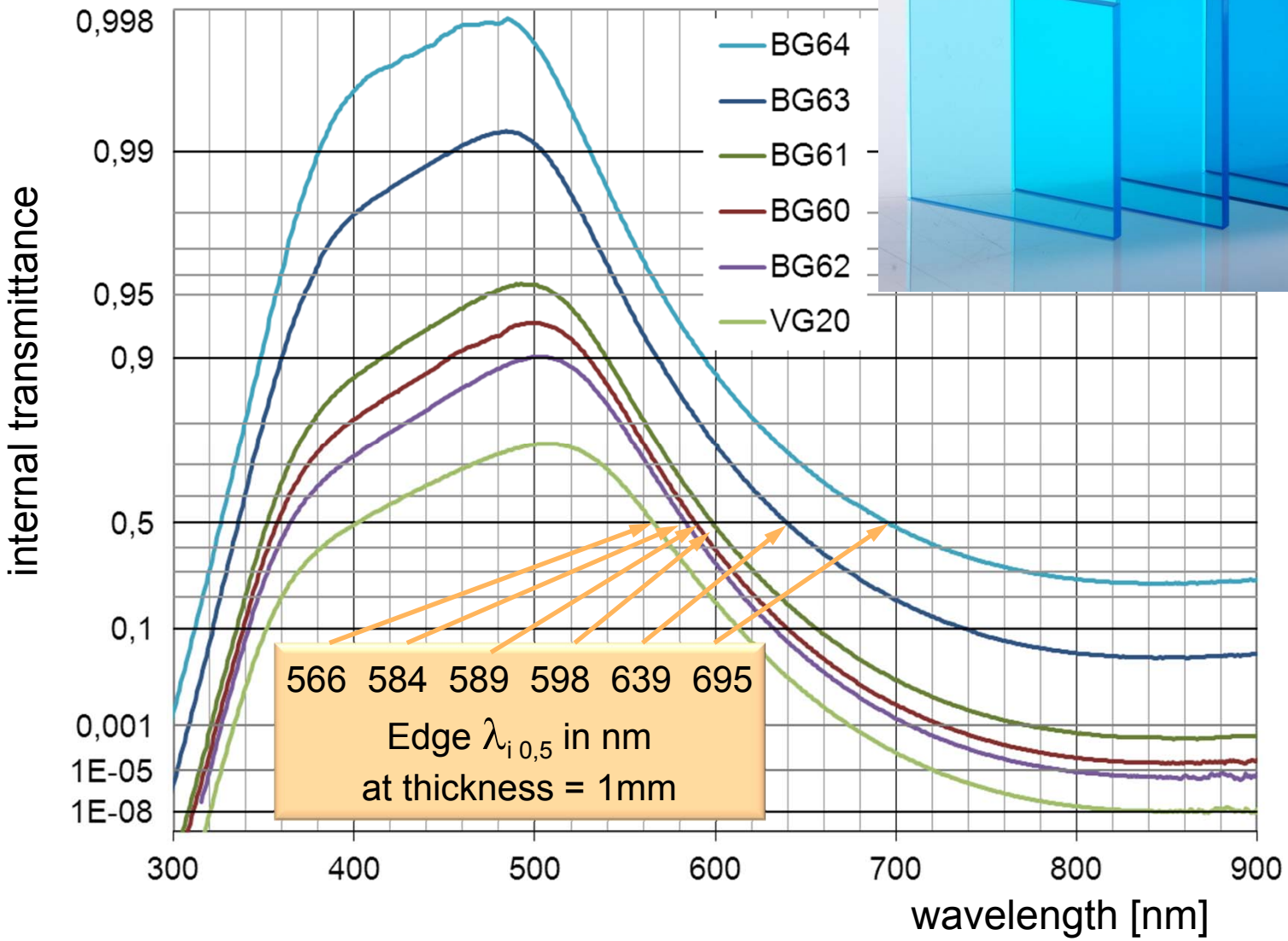
New NIR Cut-Filter





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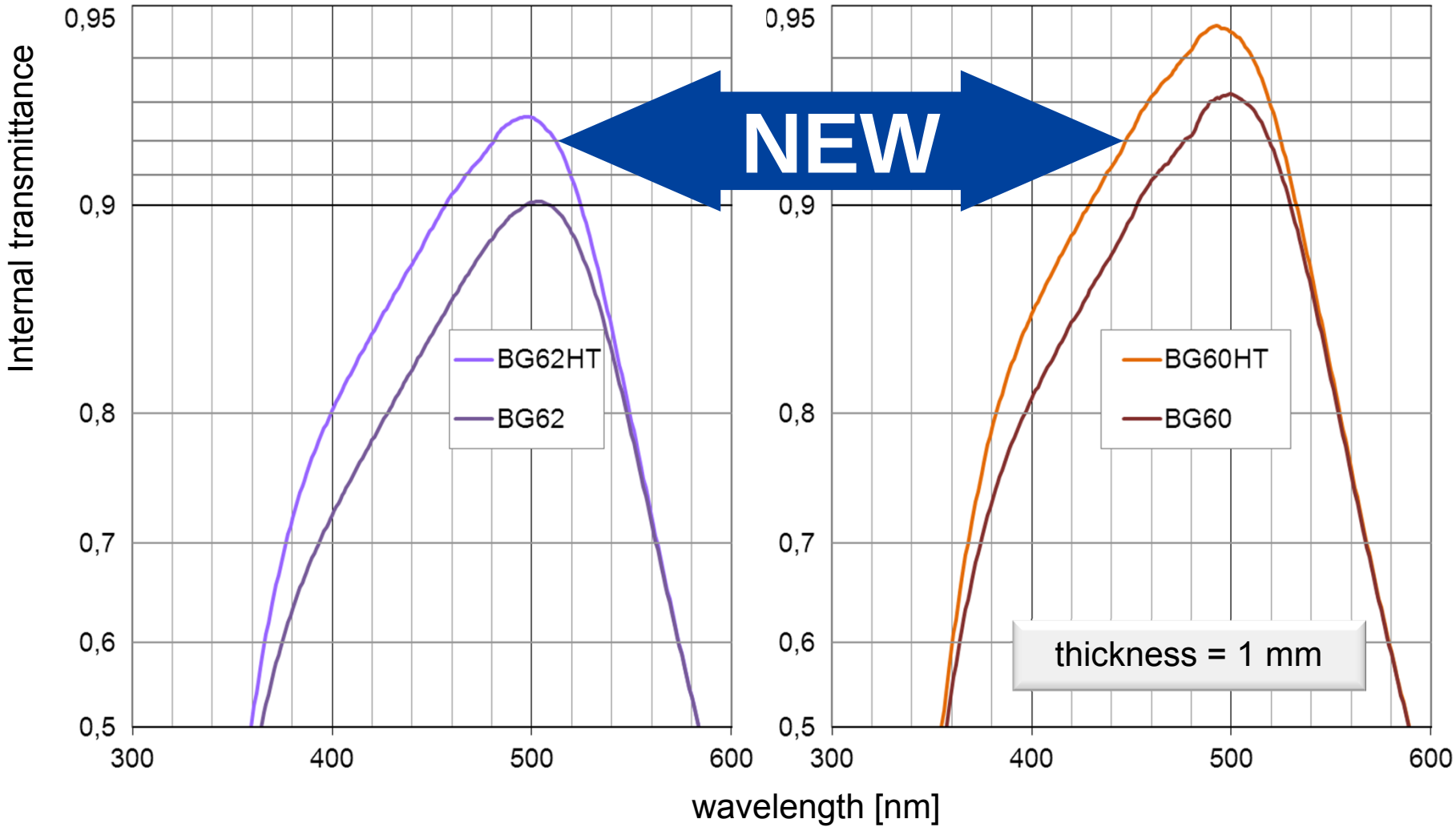
NIR Cut-Filter BG60 and BG62 in HT-Version



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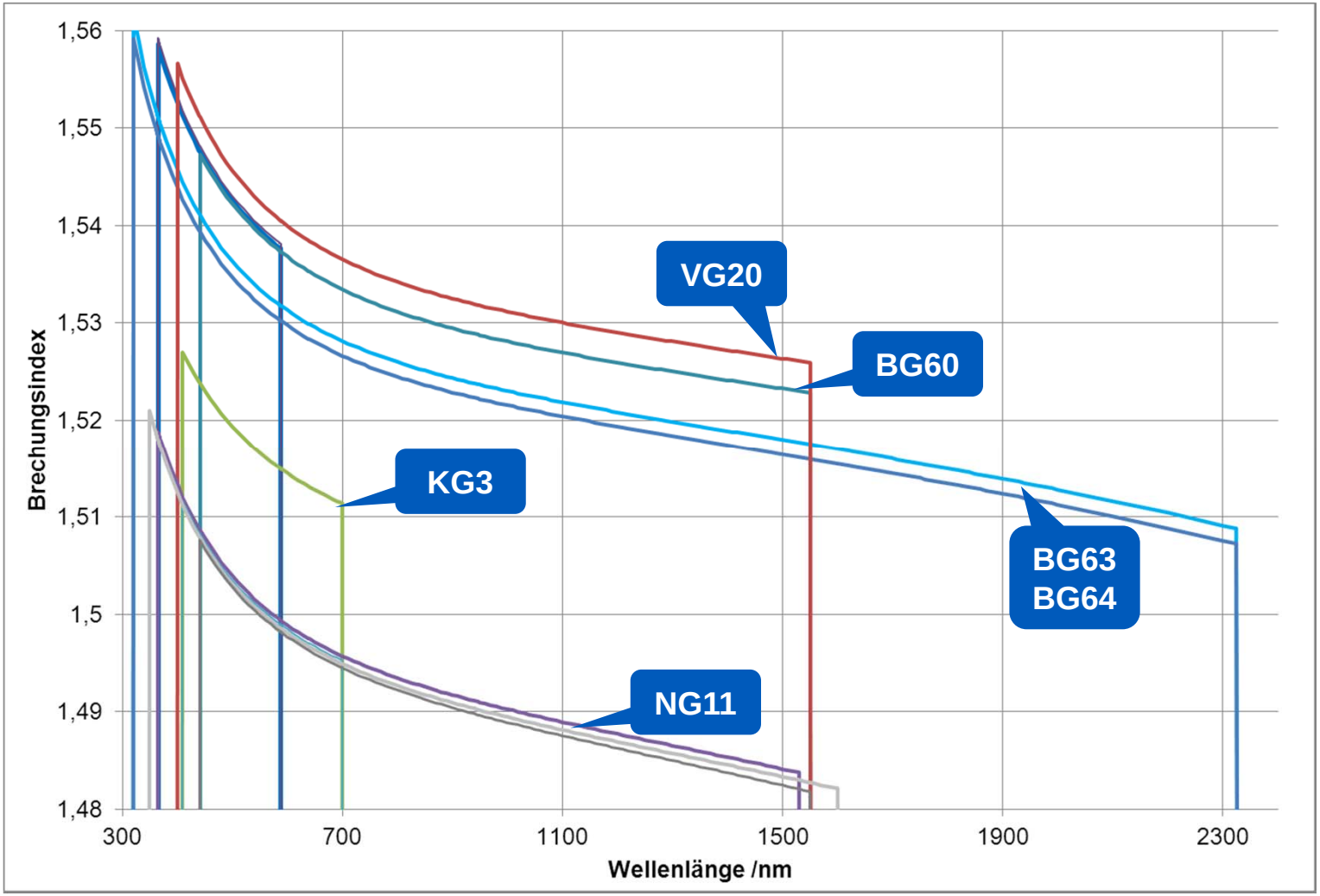
Refractive Index and Dispersion



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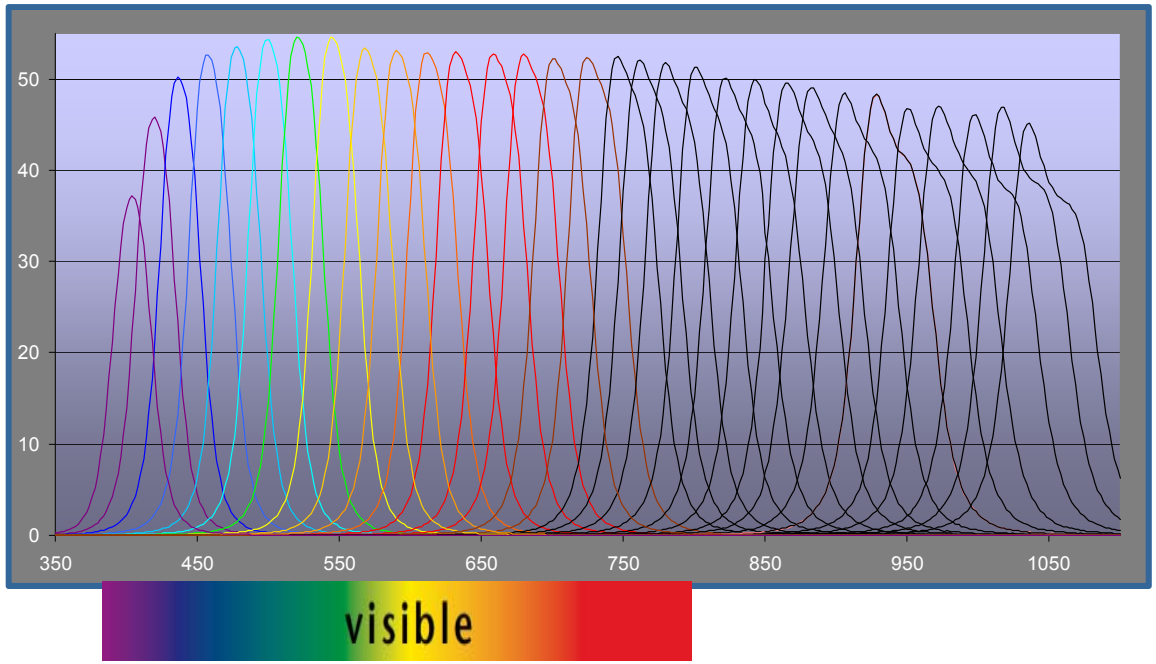
Todays interference and special filter variety covers a broad range of applications

- Bandpass filter
  - UV bandpass filter and i-line
  - UV-Vis Bandpass filter
  - Vis bandpass filter
  - Vis-NIR bandpass
  - Sets of Fluorescence Filter
- VERIL – linear variable bandpass filter
- Shortpass filter & longpass filter
- AR, broadband AR; multiband AR, scratch resistant AR
- Dielectric or Metallic mirrors
- TCO
- Black coating
- Beamsplitter
- Notch filter
- SFK filter for color measurement

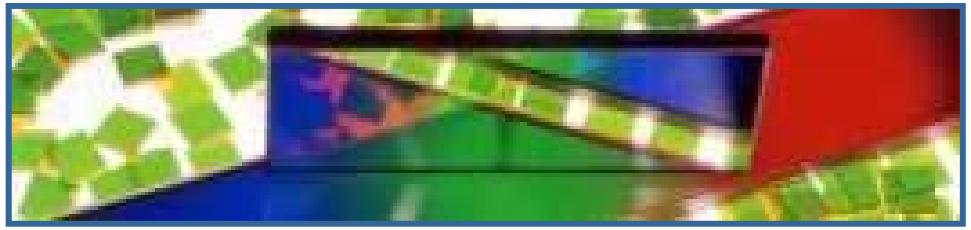
VERIL filter: a combination of filter glass + interference filter

linear variable bandpass filter

- Application: analytics
- High ratio between transmittance and absorption
- SCHOTTs superior solution: filter glass + interference filter



- Different bandpass filters at different lateral positions
- The bandpass shifts linearly over the length of the filter
- Eliminates the need for multiple filters



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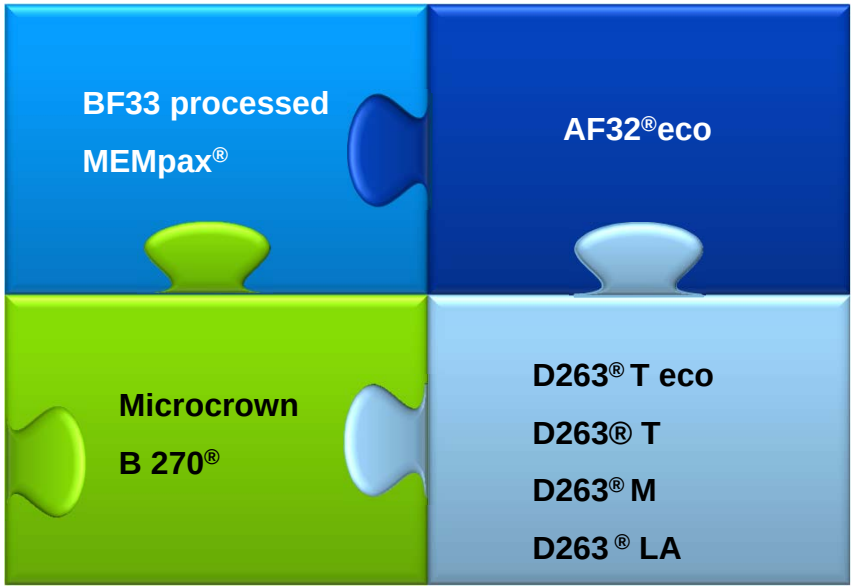
Thin Glass portfolio and typical applications

MEMS

Biotech Slides
Opto Electronics



Wafer Level Packaging

IR Cut Filter
Touch Panel
Biotech Cover Glass
Image Sensors

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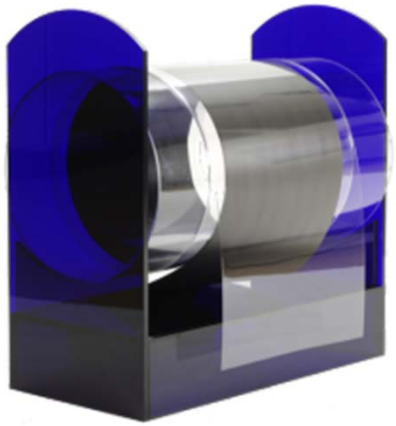
Glass type comparison chart

Material Property	Units (Notes)	MEMpax	D263T	AF32eco	B 270
Manufacturer		**SCHOTT**	**SCHOTT**	**SCHOTT**	**SCHOTT**
Thickness	mm	0.1 - 0.7	0,03 - 1,1	0.03 - 1,1	0.9 - 10
hot forming method		down-draw	down-draw	down-draw	updraw
Density	g/cc	2,22	2,51	2,72	2,55
CTE (20 – 300°C)	X 10^{-6} /°K	3,25	7,2	3,2	9,4
Transformation Point	°C	525	557	715	533
Young's Modulus	GPa = kN/mm²	63	72,9	66	71,5
Poisson's Ratio	-	0,2	0,208	0,235	0,219
Knoop Hardness	HK 0,1/20	480	590	555	542
Refractive Index	n_d	1,472	1,5231	1,5255	1,523
Transmission	%	92.7	91.7	91.9	91.7
Dispersion	$n_f - n_c$	71,9 x 10^{-4}	96,0 x 10^{-4}	84,0 x 10^{-4}	0,0089
Anodic bonding with SI	y / n	yes	no	no	no
Thermal Conductivity (90°C)	W/m°K	1,12	1,06	1,04	1,01(89°)
Dielectric Constant	@ 1 MHz/20°C	4,6	6,7	5,1	7
Loss Tangent	@ 1 MHz/20°C	0,0037	0,0061	0,0009	30* 10^{-6}

Ultra-Thin Glass: AF32 Eco and D263 T Eco



The product

- Ultra-thin glass of a thickness between 25 and 100 micron
- Proposed standard thicknesses 25 / 50 / 70 and 100 µm
- Production in a continuous down-draw process
- Delivery as cut-to-size sheet or on roll (500mm net width)
- Enabling Roll-to-Roll (R2R) processes at our customers
- Multiple coating and laminating options

Target applications / markets

- Barrier films
- Thin film batteries
- Capacitors
- Sensors
- PCB
- Window laminates
- Interposers

Project status

- Delivery of cut-to-size sheet samples ongoing
- Several hundred meters of various glass thicknesses successfully rolled and unrolled
- Several rolls of glass have been shipped to customers for R2R process trials

USPs

- Hermetical barrier
- High thermal stability
- Resistance to UV light
- Long term stability
- High transmission
- Chemical stability
- Fire polished surface
- R2R process cost savings

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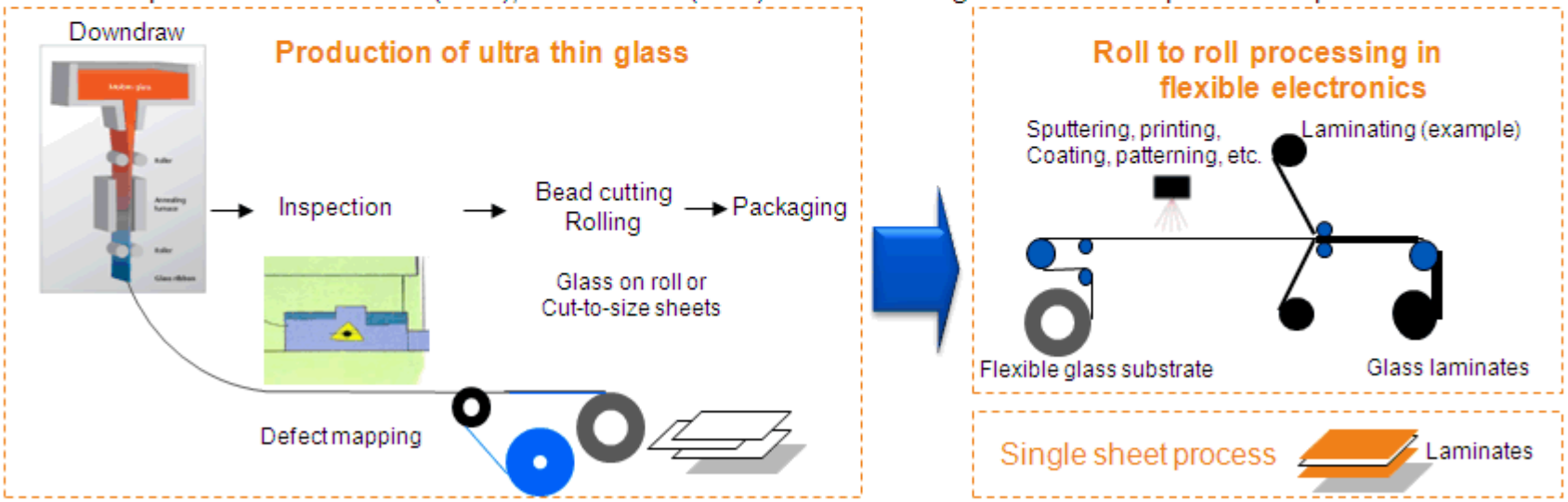
Ultra-thin glass production and post processing

Ultrathin glass production at SCHOTT

- Glasses with thickness below 100µm, down to 25µm (D263®T eco, AF32® eco)
- Produced with down-draw process in rolls and sheets
- Compatible with roll to roll (R2R), roll to sheet (R2S)

Post processing at customer (example)

- Combination with different materials to generate laminates for various purposes
- Printing or sputtering
- Singulation as final process step



Ultra thin glass on roll is enabling innovative and cost saving production technologies

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Infrared Materials

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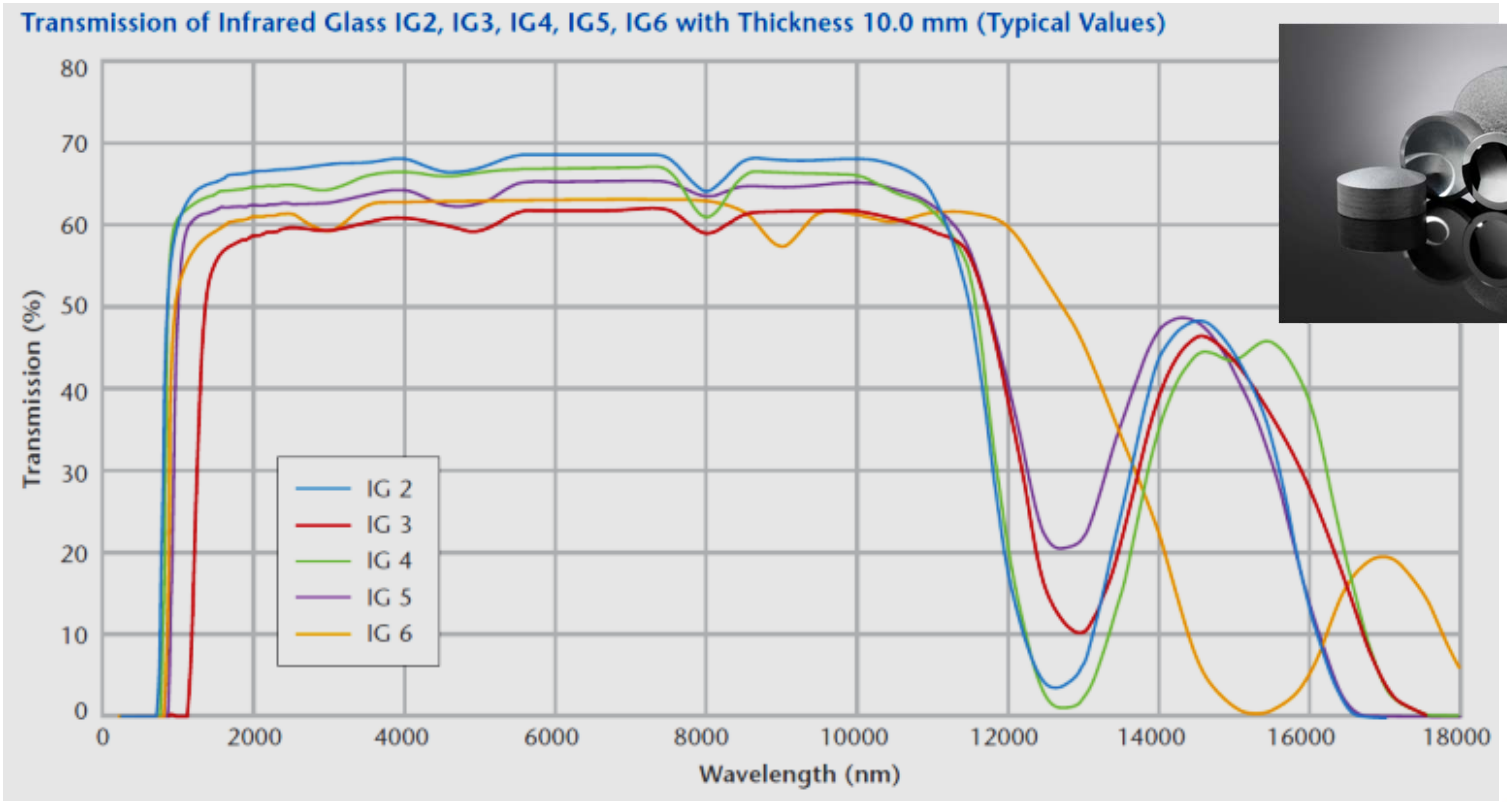
Chalcogenide glasses

- Very good transmittance
- low dn/dT
- Color correction with IG glasses

Composition

IRG 22	Ge_{33}	As_{12}	Se_{55}	
IRG 23	Ge_{30}	As_{13}	Se_{32}	Te_{25}
IRG 24	Ge_{10}	As_{40}	Se_{50}	
IRG 25	Ge_{28}		Se_{60}	Sb_{12}
IRG 26		As_{40}	Se_{60}	



Transmission at 10 mm thickness

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Chalcogenide glasses can be processed in many ways

Diamond turning

Samples, prototypes, small amounts

λ/4, 40-20, 250mm Φ,
all shapes

Precision preforms

Preforms for diamond turning and conventional grinding polishing

10λ max, concentric, 50mm Φ,
simple geometries

Lens molding

large volume applications

λ/4, 40-20, 50mm Φ,
all shapes

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Active Laser Glass for High Power Lasers

Novette, 1981-1983

NOVA 1984-1987

Beamlet 1991

NIF, 2001-2004

Laser MegaJoule, 2001-2004

The American Ceramic Society ceramics.org
R&D 100
Corporate Technical Achievement Awards

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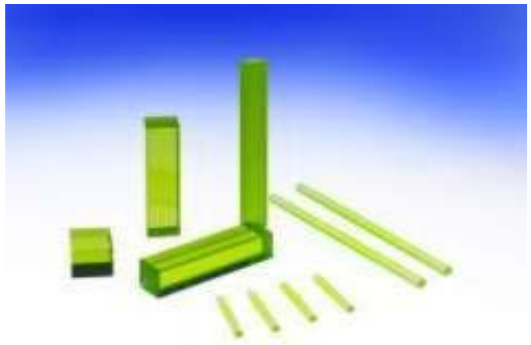
Active laser materials variety

- Silicate laser glass for standard application (LG-680)
- Phosphate laser glass for high energy application (LG-750, LG-760, LG-770)
- Phosphate laser glass for high average power and high repetition rate application (APG-1, APG-2)
- Eye-safe phosphate laser glass (LG-940)
- Ion exchange glasses for integrated optics (IOG-1, IOG-10)
- Developments are driven by past experience and systematic variation in glass component identity and amount

Phosphate Laser Glass for ‘Eye-Safe”

LG-940 for 1.53 μm lasing wavelength; Erbium - Ytterbium – Chromium-Cerium doped phosphate based laser glasses

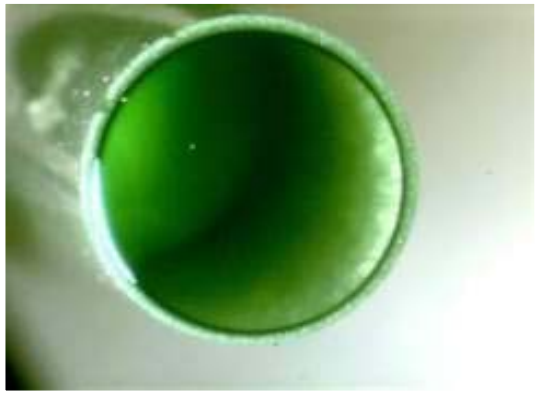
high quality laser glasses, with polish and coating
Rods, slabs or discs are manufactured to custom specifications
AR and HR coatings with high laser damage thresholds exceeding 1.5GW/cm^2



Application:

Laser range finding (defense & industrial)

Cosmetic applications (medical)



Thank you for your attention …. !