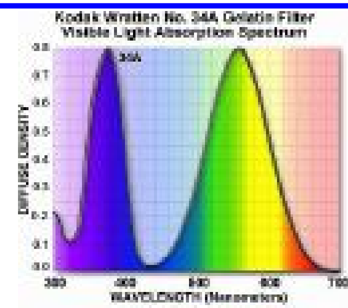
Colour Filters

by
Rodger W. Gordon
&
Chris Lord



In the 1950's in the U.S.A. and the U.K. colour filters were seldom used by amateur astronomers and those that were, were mostly war surplus that seldom fitted the eyepieces then in use. This was surprising as Zeiss sold colour filter revolvers in the 1920's and 30's and Zeiss was well established in both the U.S.A. and the U.K. before WWII. What filters were in use in the UK comprised sun and moon eye caps, as had been used for well over a century.

All this changed in the late 50's and early 60's, when the late Charles Capen published a number of articles on filters. Capen was a professional astronomer who pioneered colour filter useage and who subsequently became A.L.P.O. Mars Recorder.

The first firm in the U.S.A. to sell filters on a regular basis was Optica b/c in California. The company offered, in screw mounts, both dyed-in-the-mass glass or gelatine filters. In the UK the firm Hellma, in Westcliffe-on-Sea, Essex, offered sandwiched gelatine filters. Transmissions were based on the Kodak Wratten series, and included 58; 47B; 25A; 23A; 21: 15; 11; and a few others. Few manufacturers followed suit, though surplus filters were always available from firms like Edmund Scientific. Here in the UK, the Milton based company UQG (ref 7) has offered Schott series dyed-in-the-mass filters for over 30 years.

By the 1970's, colour filters became more popular. This was largely due to Capen's efforts and the small firm Vernonscope, who reprinted some of Capen's articles, and introduced a series of filters to fit their Brandon eyepieces. Optica b/c published *"Astro filters for Observation and Astrophotography"* in 1964 and later reprinted it in 1973 (ref 3). This 103 page volume, no longer in print, is still the standard reference on colour filter useage. Unfortunately no comparable work has appeared since.

Today many manufacturers offer colour filters in their accessory line though seldom provide adequate information on their proper useage.

Obtaining maximum performance from colour filters requires some knowledge of the reflective properties of the moon and planets. The colour index of these objects is a measure of the ‘blueness’ or ‘redness’ of their reflected light. The higher the number, the redder the light. Colour index is also a measure of the colorimetric properties of stars.

Various sources give the colour index of the moon and planets and quote slightly differing values. The data used is taken from Norton’s Star Atlas 13th. Edition 1957. As might be expected, Mars has the highest colour index of +1.45 (Arcturus is +1.48), followed by Saturn at +1.22, the moon at +1.20; Jupiter +0.96; and Venus +0.91. Uranus and Neptune are ignored in this discussion owing to their faintness.

It may come as a surprise to learn that the colour index of Saturn and the moon are almost identical and it will also come as a surprise that the moon reflects an excess of red over blue blue light; it does so by 12% vs 8%. If the moon were at the distance of Mars at perehelic opposition (35,000,000 miles), to the unaided eye it would have a yellow-orange hue just like Saturn.

By blocking certain wavelengths and allowing others to pass, the relative contrasts of lunar or planetary markings are enhanced. Orange and red filters for example block blue and are useful for study of Martian surface detail. Blue filters are useful for studying planetary atmospheres. Contrast enhancements are often dramatic. Filters also suppress irradiation, a phenomenon that is best known for its effect in extending a Martian polar cap beyond the limb. Orange and red filters give the cap(s) a less abnormal outline. Venus also suffers from irradiation which suppresses the faint upper atmospheric shadings. In this case blue or violet filters perform best of all. A classic example of how filters can alter the appearance of a planetary feature, lies in Jupiter’s ‘Great Red Spot’. With orange or red filtration the GRS practically vanishes. With a Wratten 38A blue the GRS is thrown into stark prominence.

Filters also improve resolution of some double stars. Often the difficulty in resolving a close pair is caused by irradiation from the primary overpowering the comites. Yellow and green filters often bring success. Sidgwick (“*Amateur Astronomer’s Handbook,*” Faber and Faber, 1955) pointed out that the Airy spurious disc became sensibly smaller when filtration was used, especially yellow or green. The author has confirmed this with green filters such as the Wratten 56 and 58, or Schott VG-6 and UG-9.

Rayleigh scattering causes the sky to appear blue. Blue light of 400nm wavelength is scattered 16 times more than red light of 800nm. Yellow, green, orange and red filters eliminate Rayleigh scattering. They also greatly reduce scattered light in the case where light cirrus clouds or mist, fog or smog scatters moonlight which otherwise markedly reduces contrast. Gold coated diagonal mirrors also achieve the same effect.

Colour filters are the most cost effective way to dramatically reduce or eliminate chromatic aberration in achromatic refractors. Again yellow, green, orange and red filters are very effective here as are gold coated diagonal mirrors. In the late 1970's broad-band interference filters were introduced. Recently a filter of this type designed to reduce secondary spectrum by 80% - 85% has been offered for less than $100. Some theoretical optical designers and apochromat manufacturers have built up secondary spectrum into a nightmarish curse to be avoided at all costs (*your cost!*), whereas in actuality the contrast and light losses from the typical crown-flint doublet is less than that incurred from a central obstruction of 20% diameter; something that most observers are willing to tolerate. The most "*outstanding*" property of ED glass and Fluorite crystal is its ability to remove the excess green in the purchaser's wallet!! This writer has owned two apochromats and observed with a number of others including Zeiss APQ's. While there is no doubt that the contrast of the APO is higher than the equivalent achromatic, the APO's advantage vanishes when a $15 - $20 colour filter of the appropriate choice is introduced to the achromatic's optical system. Even if filters are used with apochromatics (and filters should be used with all types of telescope in order to obtain maximum contrast levels), the contrast level of apochromatics and achromatics equipped with the same filter(s) are of negligible difference and in no case warrent an additional outlay of several hundred or thousands of green and folding.

An amusing incident (but not to APO manufacturers) occurred in the 1980's when a few optical designers tested some APO's on Vega and then criticized them because they showed a very small amount of secondary spectrum. The tests were conducted at 140x per inch of aperture! A magnification seldom encountered in any observing scenario. These same individuals are also among the, "*less than 50x per inch crowd*" at star parties, yet apparently have no qualms about using almost triple that to nitpick the products in question! One can only boggle at the unthinking prejudice behind such ludricrous posturing.

The use of filters (especially those in the orange - red region) or a gold coated diagonal mirror or star diagonal can increase contrast by 80% - 100% or more. Although this writer uses the Wratten series (by Vernonscope), in some instances he often prefers the Schott series filters such as OG-530 and VG-6. VG-9 is also a very good filter for apertures greater than 8-inches. An overlooked filter (for Mars) is the Wratten 30 magenta, which allows simultaneous viewing of both surface and atmospheric features. It is only offered by Vernonscope, but can be provided with an adaptor to use on non-Brandon $1^1/_4$-inch eyepieces.

Sometimes combining filters can be useful though larger apertures benefit most because of the significant light loss. However, the author often combines Schott OG-530 yellow with a gold coated star diagonal on his 1986 model 4-inch f/5.5 Renaissance and contrast levels are quite adequate on the moon and Mars at well over 200x.

With the absence of in depth information of colour filters in astro use, the most reliable source of filter info and data is Eastman Kodak's booklet, "*Color Filters for Scientific and Technical Use*"(ref 5). Vernonscope will provide on request a copy of Capen's paper on colour filter usage and recommendations. Include postage and a stamped self-addressed envelope when contacting Vernonscope. Large photographic outlets may have copies of the Kodak booklet in stock, or may be able to order it for you.

Neutral density and polarizing filters are helpful in reducing glare, for example when observing Venus, the Moon, and occasionally Mars. Many suppliers offer variable density polarizers in which transmission can be adjusted to match the object under study. In WWII, variable density polarizing goggles and ND filters were standard fare with fighter pilots, and could mean the difference between life and death. No fighter pilot took off without them.

It is a matter of debate whether it is good practice to employ colour filters to reduce brightness levels to any marked extent. Unfortunately few manufacturers provide three different density steps per colour, except for ND. Colour filters are often used to facilitate detection of lunar transient phenomena, but their useage in this field is also fraught with difficulty. Not with the filters per se, but with the interpretation of what is observed.

Colour filters open up a vast arena of astronomical observational opportunities and for experimentation, but one should have a sound observing background prior to undertaking them. Of all the accessories offered by telescope dealers and suppliers, colour filters are by far the most cost effective.

Broad band and narrow band interference filters (sold as "*nebula filters*") may be put to some use as lunar and planetary filters although there is little published information available currently. Also dichroic transmission filters may be used in conjunction with a circular polarizer to selectively pass a broad band of the spectrum from deep blue to deep red.

By increasing relative contrast between adjacent areas colour filters permit more detail to be seen, this is also true in the field of astrophotography. The human eye can detect contrast differences of as little as 5% and very skilled observers with excellent eyesight may at times be able to detect contrast differences as low as 2%. Filters enhance minimal contrast differences permitting even lower white light contrast thresholds to be breached. Using selective filtration in the fields of lunar and planetary observation, it is perfectly feasible to detect low contrast detail undetectable using either conventional photography, or digital image recording techniques.

It may reliably be stated that no observer ever obtained the full contrast potential of their telescope without employing colour filters. Colour filters have in reality been in use for well over 150 years (in the C19th they were referred to as “*colour screens*”). As an interesting historical footnote, not long after the invention of the telescope, smoked glass was used as a neutral density filter in an attempt to suppress the false colour that accompanied the simple single element object glasses of the day.

And now to the practicalities:

A direct vision prismatic pocket spectroscope with an adjustable slit, such as those which used to be made by Browning, Cooke, Zeiss, or Goto, and currently made by Edmund Scientific, are very useful in checking the quality of a colour filter. It is not uncommon for blue filters to leak in the far red. This may be of no consequence for most types of visual work, but can be a nuisance when observing Venus at night for example.

The mounted glass filter sets offered by dealers for Meade and Celestron are intended to fit their ranges of eyepiece in the 1 $^1/_4$-inch or 2-inch push fit standard. The snag is if you wish to compare for instance an orange and pale blue filtered view of Mars, or a red and blue view of Venus, Jupiter or Saturn. It then of course becomes necessary to remove the eyepiece and switch filters. It is possible to purchase rotary filter holders into which these filters may be screwed. The problem with these, apart from their cost, is that you cannot see the filters.

The ideal solution is a custom built filter slide as used by Chris Lord. Ron Irving made this to his specification. It accepts $^3/_4$-inch O.D. by 1mm thick filters. He has three different slides, each holding eight Schott series filters, graded in light, medium and deep colours. This is not as costly as it sounds. The slide and holder cost £80 and each filter set cost £45 including the crown plain filter for the white light view at the end of each slide. The filters were selected by Martin Gautrey of UQG (see ref.7) and each filter was supplied with a spectrophotometric trace.

If you are in the habit of keeping your filters in an observatory be aware that either gelatine, or sandwiched gelatine filters will absorb moisture from the air. It has been Chris Lord's costly experience that even hermetically sealed sandwiched gelatine filters will delaminate. A Wratten series set supplied by Hellma in 1988 quickly deteriorated during the autumn months of 1990. Hellma replaced them at a cost of £70 in December 1990. They lay, unopened in the box in which they were posted until May 2001, when they were fitted into a brass filter slide. Despite that month being mostly dry, warm and sunny, and the slide being kept in a hardwood pencil case with a very tight lid, by the end of the month the etalons had begun to part company! If you decide to buy the Wratten series gelatine filters, keep your filters indoors in a cool, dark, dry place. If you prefer leaving all your kit in the dome, the only answer to this problem is to use glass filters, in which case the Schott or Hoya series filters are the best option.

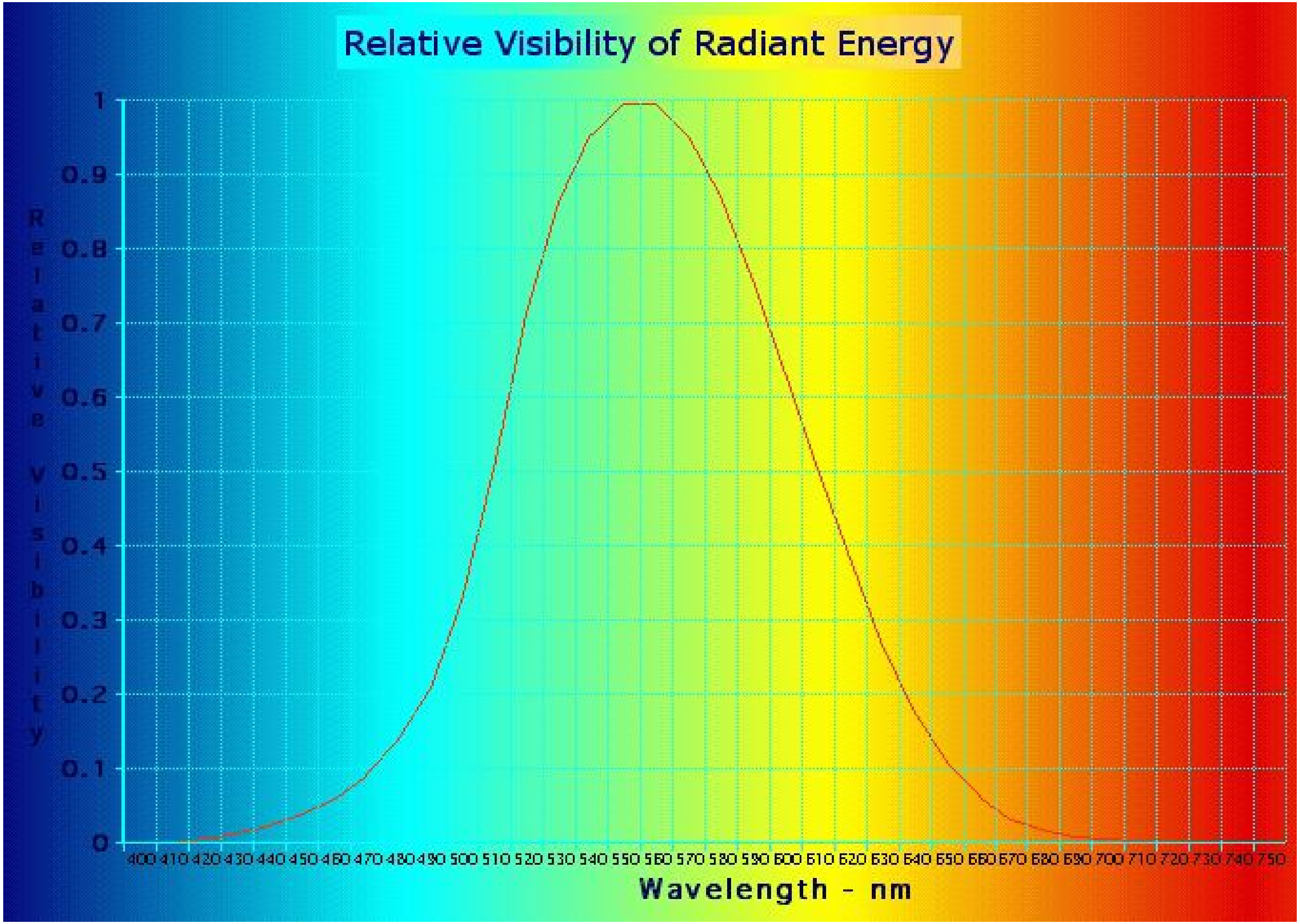
Selecting an appropriate filter set:

Filters need to be selected so you end up with a matched set of transmissions that look more or less the same density. This is not quite as straightforward as some tyros seem to think. It is not simply a matter of choosing a filter set by selecting filters of differing colours with approximately similar transmittance. The reason for this is the eye's spectral response, which peaks at 555nm in the yellow-green. The apparent opacity and colour saturation of a particular filter depends upon its transmittance characteristic and that of the eye. Matching filter colours is as much an art as it is a science and it is best left to the expert.

Relative Visibility of Radiant Energy*

λ	Visibility	λ	Visibility	λ	Visibility
400	0.0004	520	0.7100	640	0.17500
410	0.0012	530	0.8620	650	0.10700
420	0.0040	540	0.9540	660	0.06100
430	0.0116	550	0.9950	670	0.03200
440	0.0230	560	0.9950	680	0.01700
450	0.0380	570	0.9520	690	0.00820
460	0.0600	580	0.8700	700	0.00410
470	0.0910	590	0.7570	710	0.00210
480	0.1390	600	0.6310	720	0.00105
490	0.2080	610	0.5030	730	0.00052
500	0.3230	620	0.3810	740	0.00025
510	0.5030	630	0.2650	750	0.00012

* *From Bureau of Standards Scientific Paper 475, p. 174.*


Relative Visibility of Radiant Energy
Relative Visibility
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700 710 720 730 740 750
Wavelength - nm

Recommended filter sets for lunar and planetary use:

Schott:

Broad Band	Mid Band	Narrow Band
OG570	OG590	RG695
OG550	OG570	RG645
OG515	OG530	GG495
GG475	GG455	GG435
BG39	BG7	BG18
BG25	BG13	VG14
BG3	BG12	VG5
	VG6	

transmittance curves for all Schott colour filters are in the appendix

UQG can also supply the following narrow cut specials:
No2 + B270$_{1.0}$ violet
No3 + GG420$_{1.0}$ blue
No4 + GG455$_{1.5}$ green
UG1 + SpecB ultraviolet

Meade and Celestron offer filter sets; in the case of Meade, Series 4000, and in the case of Celestron, Series 1 or Series 2 or Series 3. However neither offer a complete set in any particular series. The following combination of the two is ideal for mid-aperture telescopes:-

Eyepiece Series	Filter Type	Colour & Opacity
Meade Series 4000	Wratten #25A	red - transmittance 14%
Celstron Series 3	Wratten #23A	light red - transmittance 25%
Meade Series 4000	Wratten #12	yellow - transmittance 74%
Meade Series 4000	Wratten #11	yellow-green - transmittance 78%
Celestron Series 3	Wratten #58	green - transmittance 24%
Celestron Series 38A	Wratten #38A	dark blue - transmittance 17%
Meade Series 4000	Wratten #47	violet - transmittance 3%
Meade Series 4000	Wratten #82A	light blue - transmittance 73%

The following notes are abstracts from the relevant Meade and Celestron data sheets:-

#25A - stongly blocks the transmission of blue and blue-green wavelengths, resulting in very sharply defined contrast between, for example, blue-tinted cloud formations on Jupiter and the lighter-toned features of the disc. Also useful for delineation of the Martian polar ice caps and maria. Because of its relatively low total light transmission, the #25A should be employed on telescopes of 8″ aperture and larger.

Celestron offers #25 14% transmittance in its Series 2 set -
Moon_Slightly improves lunar features.
Jupiter_Useful for studying the bluer clouds.
Mars_Ideal for observation of the polar ice caps and features on the Martian surface. Also sharpens the boundaries of yellow dust clouds.
Mercury_Improves observation at twilight when the planet is low near the horizon and in daylight reduces the brightness of the blue sky to enhance surface features.
Saturn_Useful for studying the bluer clouds.
Venus_For daylight observing. It reduces the brightness of the blue sky. Occasionally deformations of the terminator are visible.

Meade offer #23A light red 25% transmittance, and Celestron (Series 1 set) and Meade both offer #21 orange 46% transmittance - On telescopes of 6” aperture and larger, the #23A does approximately the same functions as the #21 filter, but with stronger contrast enhancement of marginally defined blue-green surface detail. Useful primarily on Jupiter, Saturn and Mars. Increases contrast between Mercury and bright blue sky during daylight observations or during twilight.
Moon_Greatly enhances lunar features.
Jupiter_Improves structure of the Jovian belts and enhances festoons and the polar regions.
Mars_Reduces the light from the blue and green areas which darkens the maria, oases and canal markings while lightening the orangeish desert regions. Also sharpens the boundaries of yellow dust clouds.
Mercury_During daylight observing reduces the brightness of the blue sky to enhance surface features.
Saturn_Improves structure of the Saturnian bands and bluish polar regions.
Venus_During daylight observing reduces the brightness of the blue sky.

#12 - Contrasts strongly with blue-colored features on Jupiter and Saturn, while enhancing red and orange features. Lightens red-orange features of Mars, while reducing or blocking the transmission, and thereby increasing the contrast, of blue-green areas. Useful in increasing the contrast of lunar features in telescopes 6” aperture and larger.
Moon_Enhances lunar features.
Jupiter_Penetrates and darkens the atmospheric currents containing low-hue blue tones and enhances the orange and red features of belts and zones. Also useful for studies of the polar regions.
Mars_Reduces the light from the blue and green areas which darkens the maria, oases and canal markings while lightening the orangish desert regions. Also sharpens the boundaries of yellow dust clouds.
Saturn_Penetrates and darkens the atmospheric currents containing low-hue blue tones and enhances the orange and red features of bands and zones.
Venus_Reveals low-contrast surface features.

#11 - Contrasts well with the red and blue characteristics of surface features on Jupiter and Saturn. Darkens the maria visible on Mars.

#58 - Use on telescopes of 8” aperture and larger to reject blue and red-toned structures in the atmosphere of Jupiter and thereby increase their contrast relative to lighter parts of the disc. Also use for enhancement of Saturn’s cloud belts and polar regions. Strongly increases contrast of Mars’ polar ice caps, and increases contrast of atmospheric phenomena on Venus.

#38A - A popular filter for study of Jupiter's disc, owing to the filter's strong rejection of red and orange wavelengths. Increases contrast between the reddish belt structures and enhances detail of the Great Red Spot. Also useful for study of isolated phenomena, such as dust storms on Mars, as well as the belt structures of Saturn. Increases contrast of subtle cloud markings on Venus.

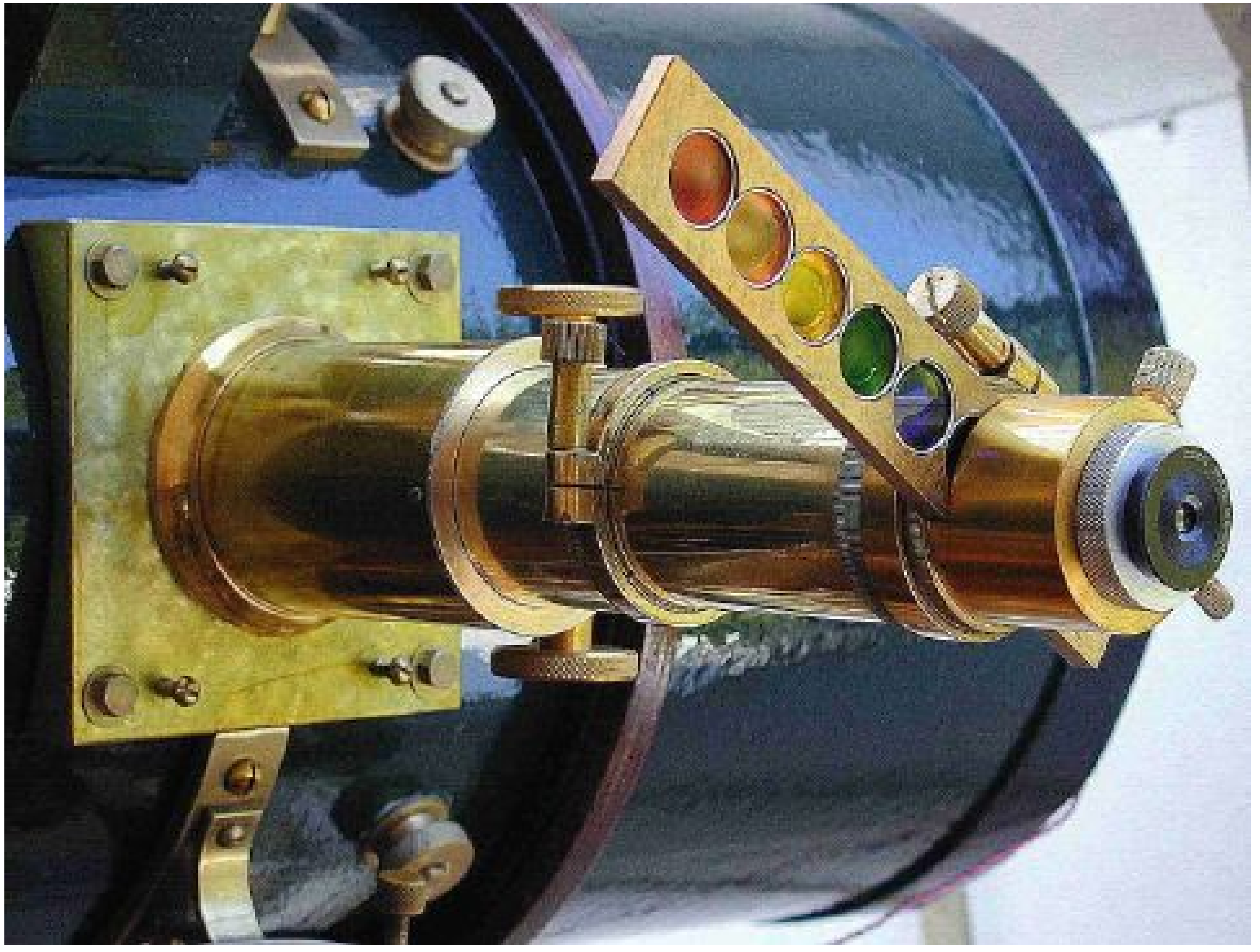
#47 - Strongly rejects red, yellow and green wavelengths; useful for the study of Martian polar cap regions, and for the observation of occasional phenomena in the upper atmosphere of Venus. Enhances contrast between the rings of Saturn. Use only on telescopes of 8″ aperture and larger.

#82A - Useful on the Moon, Mars, Jupiter and Saturn, this subtle pale blue filter enhances areas of low contrast while avoiding significant reduction of overall image brightness.

Detailed view of the filter slide fitted to the rackmount of Chris Lord's 10-inch Calver. The filters are Schott dyed-in-the-mass glass, 1mm thick, $^3/_4$-inch diameter, supplied by UQG.

The filter slide can be pushed gently through the eyepiece adaptor barrel, but is prevented from falling out by a ball headed grubb screw.

Filters are located in counterbored holes machined using a pin cutter, and held with stainless wire rings.



References:

1. Sidgwick, J.B., Amateur Astronomer's Handbook, Faber & Faber, 1955.

2. Paul, Henry, Telescopes for Sky Gazing, Amphoto Press, 1955.

3. Barbera, Capen, Carvalho, Steeg, Astro-filters For Observation and Astrophotography, Optica $^{b}/_{c}$,1973.

4. Roth, Gunther, D., Astronomy - A Handbook, Springer-Verlag, 1972.

5. Eastman Kodak, Filters for Scientific and Technical Use, now re-issued as:
   Kodak Photographic Filters Handbook, Publication No. B-3 Eastman Kodak Company, Rochester, New York (1990).
   To order go to:
   http://www.amazon.com/exec/obidos/ASIN/0879856580/102-0075142-0776150
   http://www.tiffen.com/Kodak%20Professional%20Accessories%20catalog.pdf
   http://www.allbookstores.com/book/0879852828

6. Roth, Gunther, D. Handbook for Planet Observers, Faber & Faber, 1970.

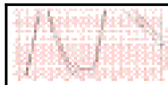
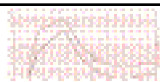
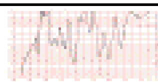
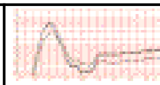
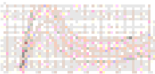
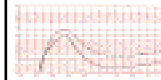
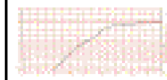
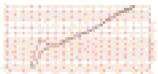
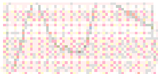
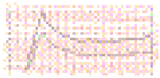
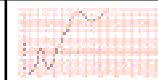
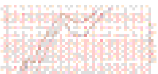
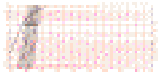
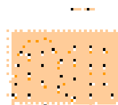
7. UQG Optics Ltd., The Norman Industrial Estate, 99-101 Cambridge Road, Milton, Cambridge, CB4 6AT,.
   tel: +44 (0) 1223 420329, e-mail: martin.gautrey@uqg.co.uk, website: http://www.uqg.co.uk

8. Eyepiece filters: goto: http://www.handsonoptics.com/color_filters/color_filters.html

9. For general Wratten series transmission data go to:
   http://www.olympusmicro.com/primer/photomicrography/bwfilterchart.html

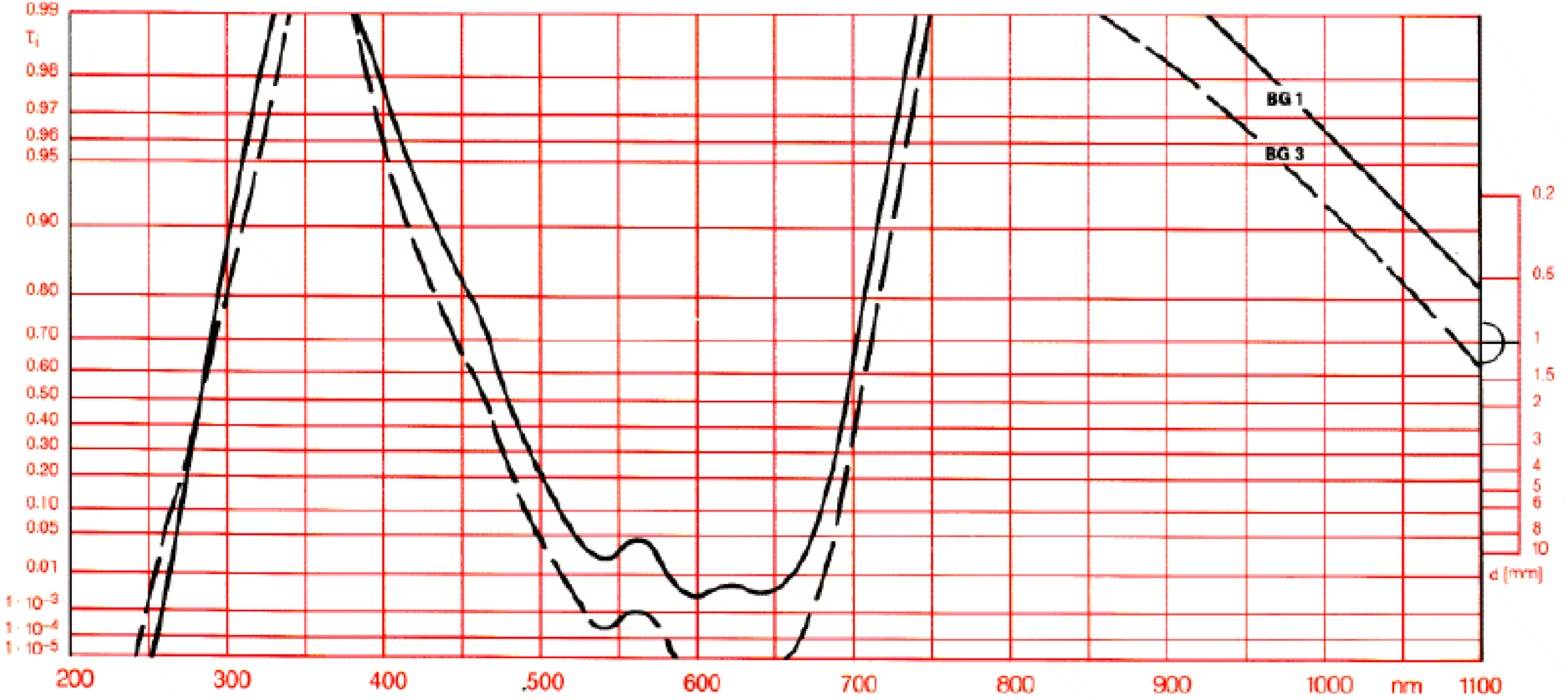
Appendix:

Schott series transmission curves for dyed-in-the-mass glass filters:

 BG1	 BG18	 BG20	 BG24	 BG25
 BG26	 BG36	 BG40	 BG7	 FG13
 FG15	 FG3	 FG6	 GG19	 GG375-RG1000
 GG4	 KG1-KG5	 KG11R-KG51R	 NG1-NG12	 UG1
 VG4	 VG6	 WG225-WG360	 s8612	 UG1 DATA

Appendix:

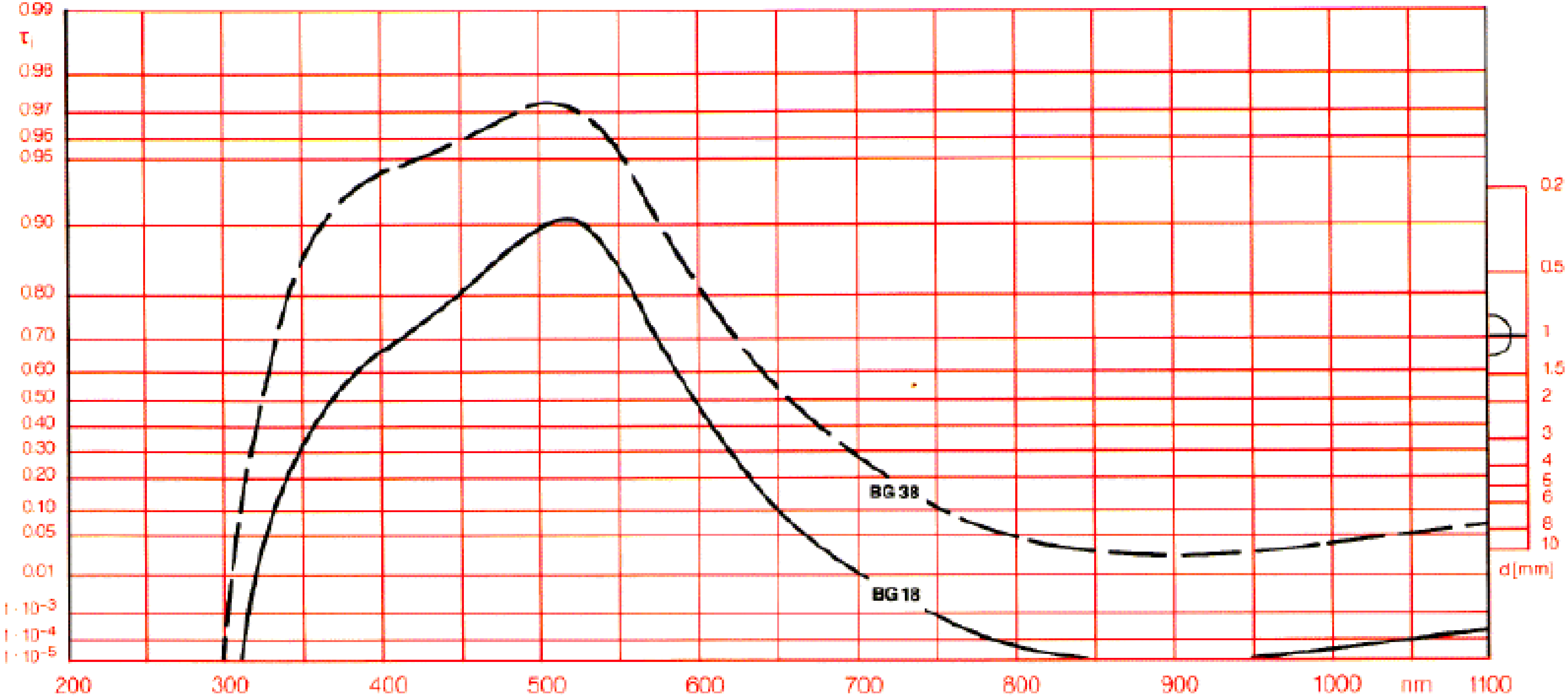
Schott series transmission curves for dyed-in-the-mass glass filters:



BG1 & BG3

Appendix:

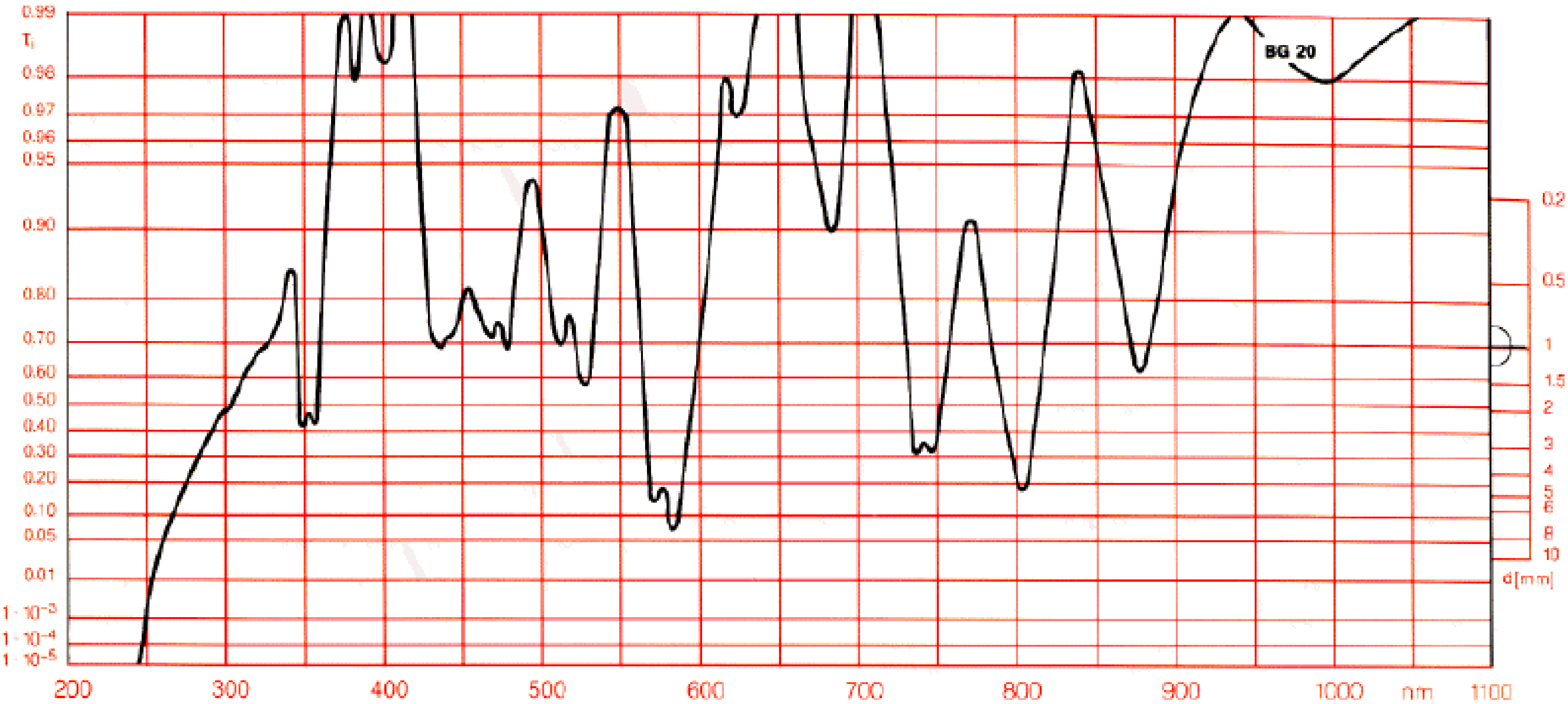
Schott series transmission curves for dyed-in-the-mass glass filters:



BG18 & BG38

Appendix:

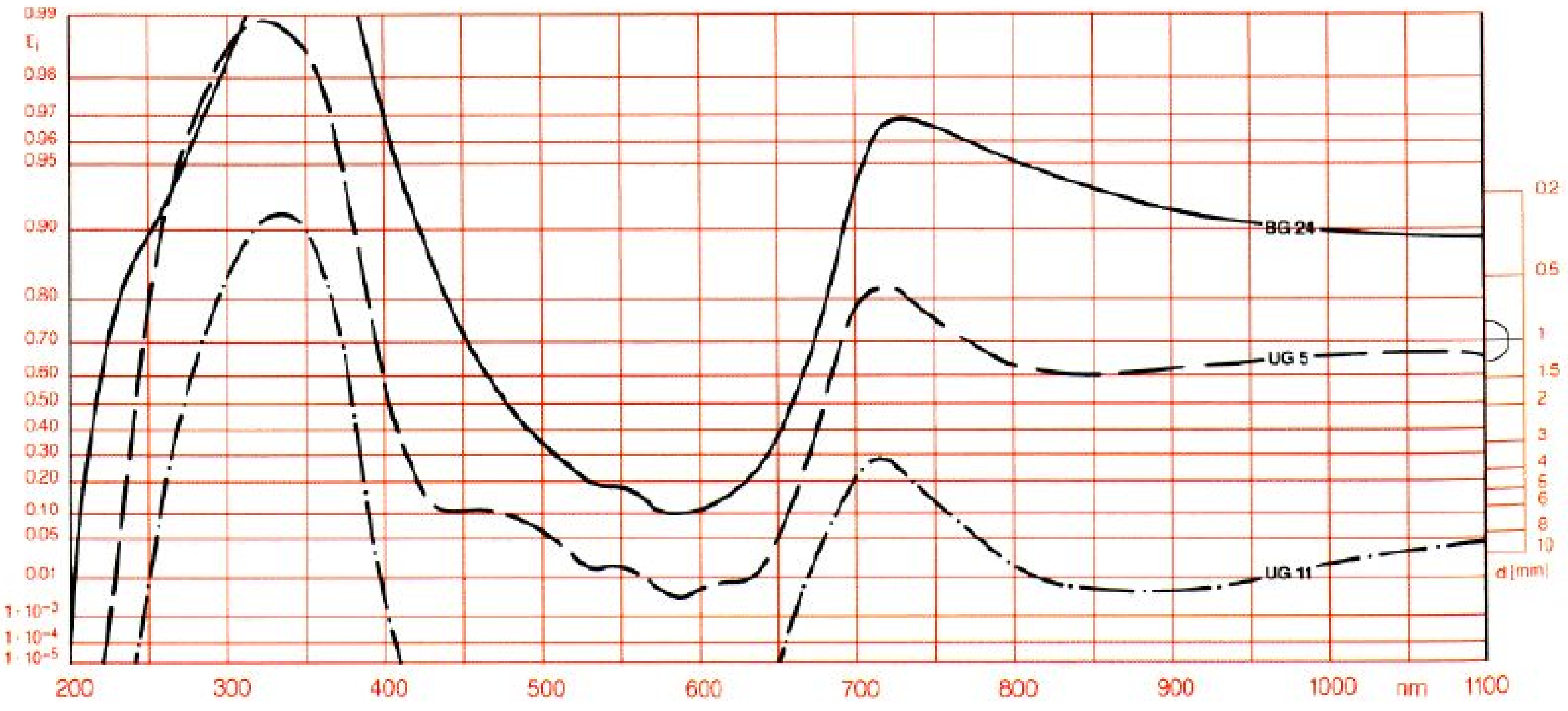
Schott series transmission curves for dyed-in-the-mass glass filters:



BG20

Appendix:

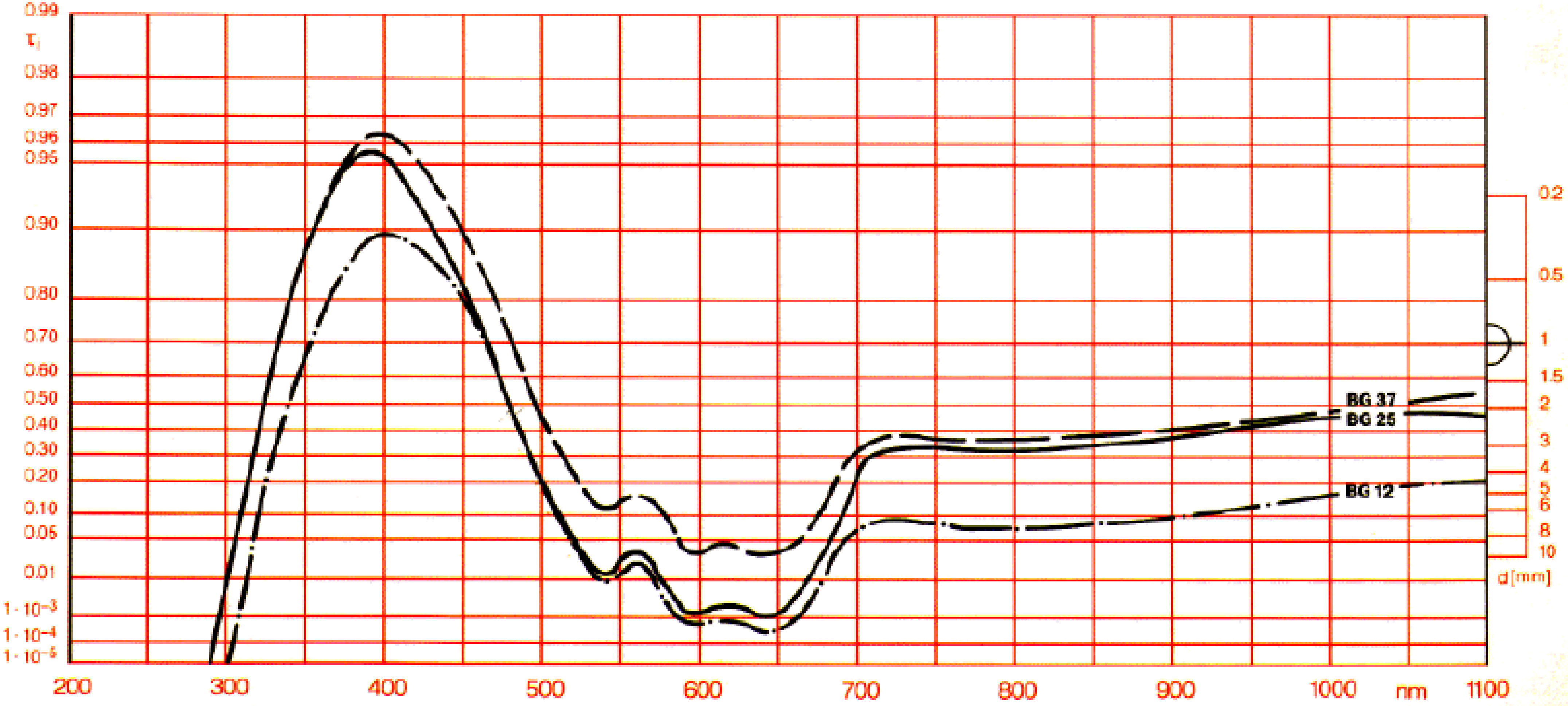
Schott series transmission curves for dyed-in-the-mass glass filters:



BG24; UG5; UG11

Appendix:

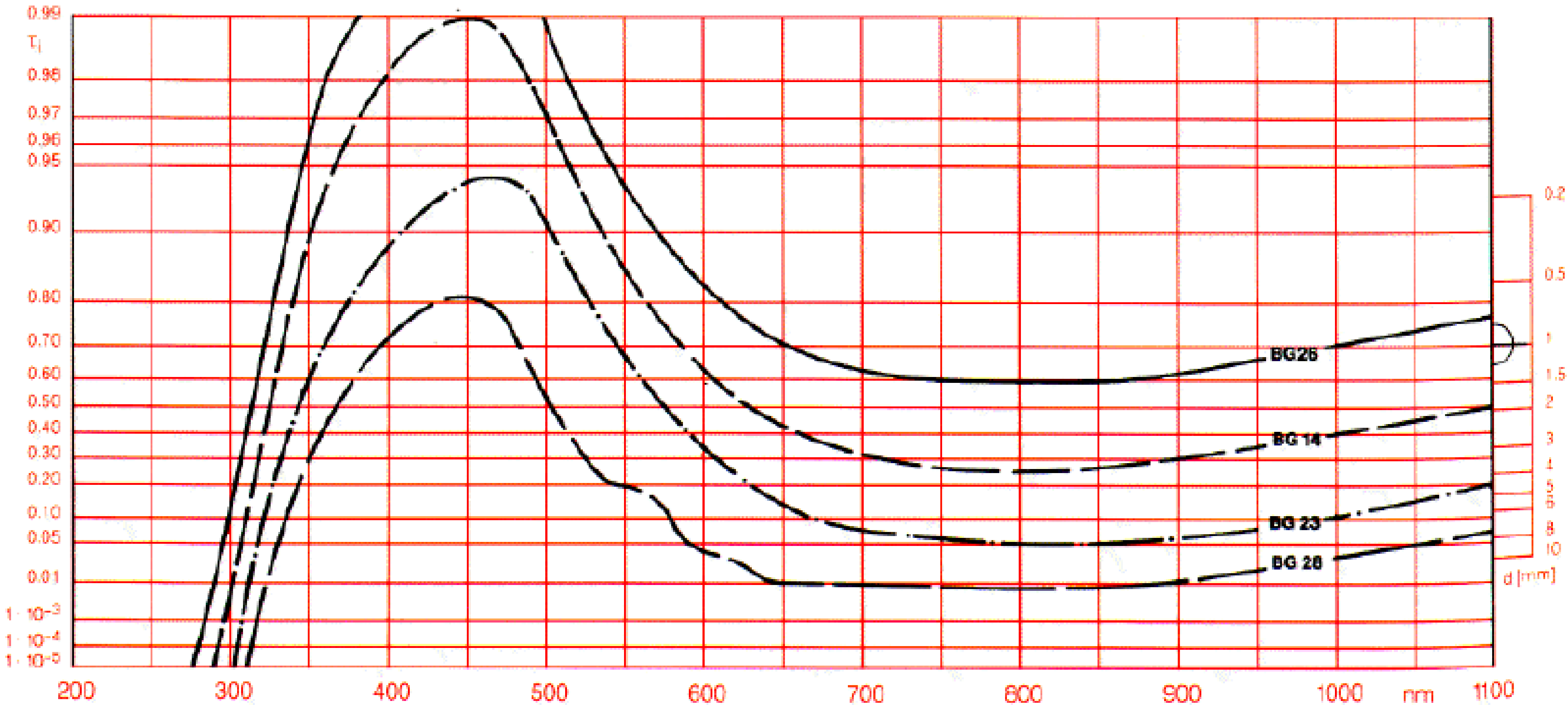
Schott series transmission curves for dyed-in-the-mass glass filters:



BG12; BG25; BG37

Appendix:

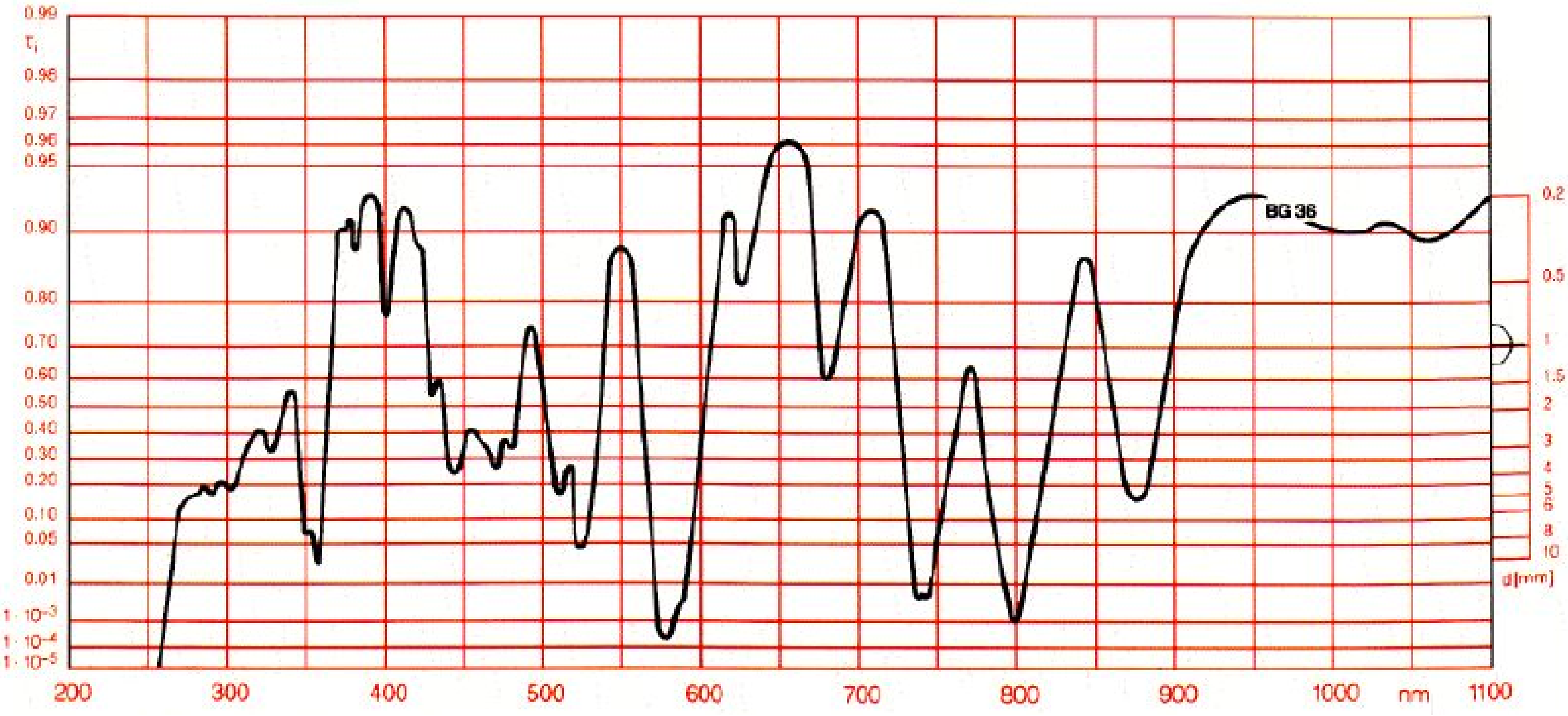
Schott series transmission curves for dyed-in-the-mass glass filters:



BG26; BG14; BG23; BG28

Appendix:

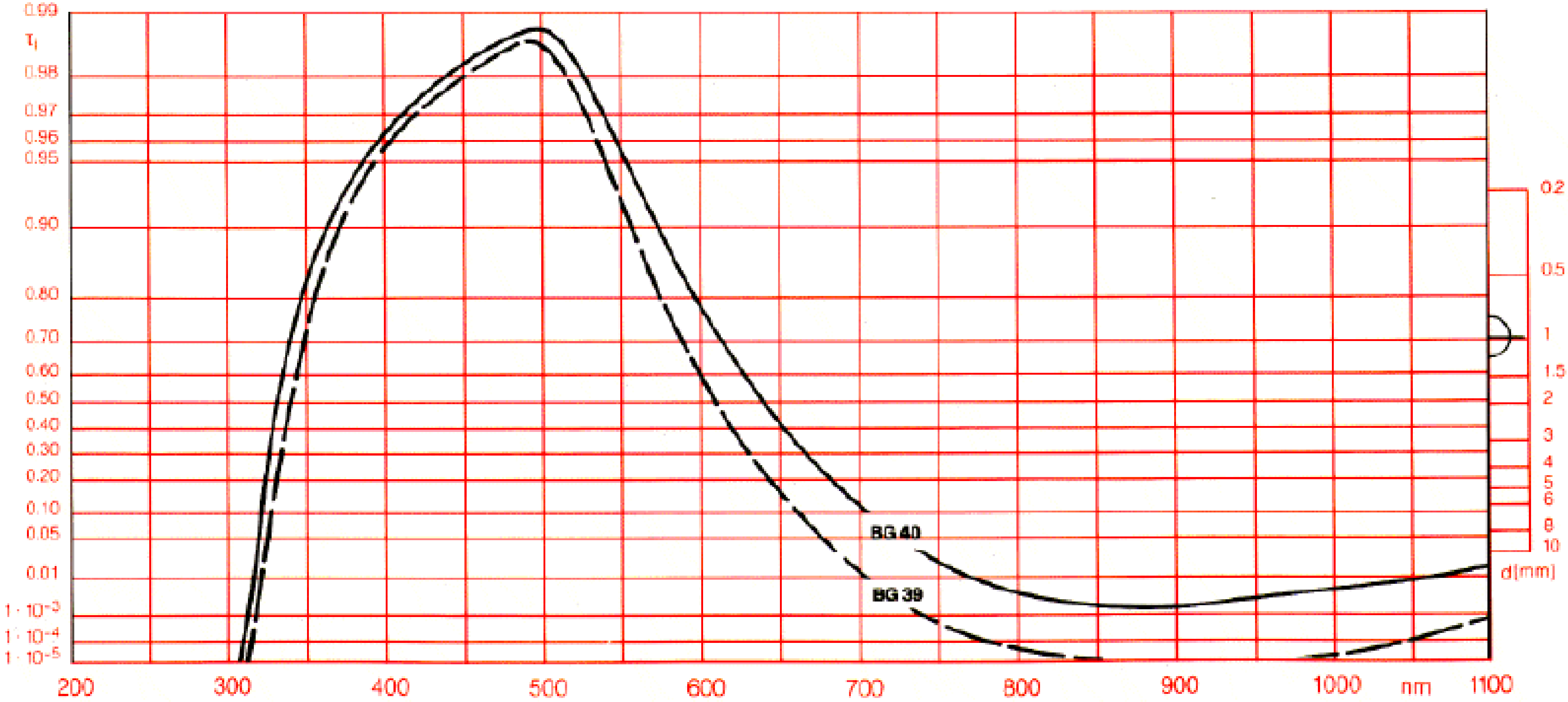
Schott series transmission curves for dyed-in-the-mass glass filters:



BG36

Appendix:

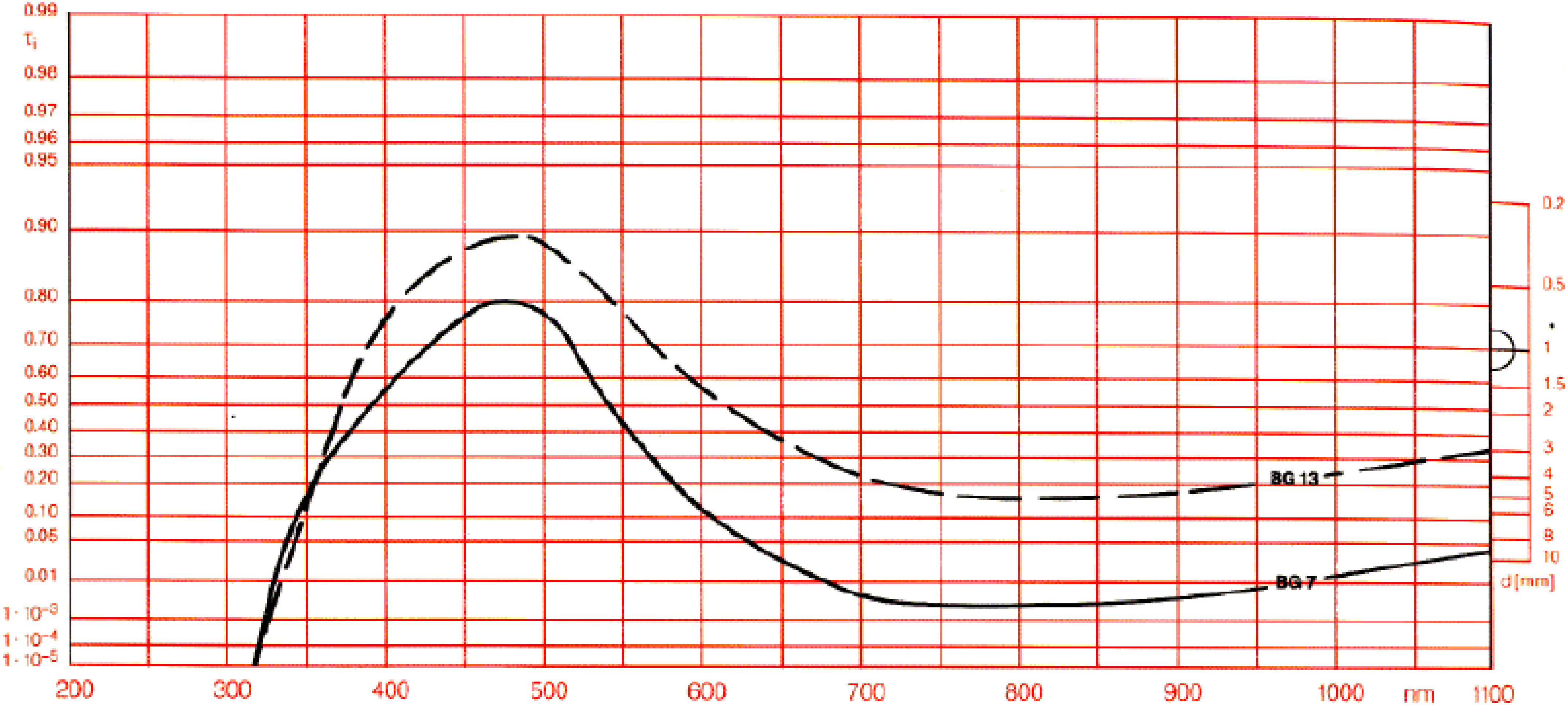
Schott series transmission curves for dyed-in-the-mass glass filters:



BG40; BG39

Appendix:

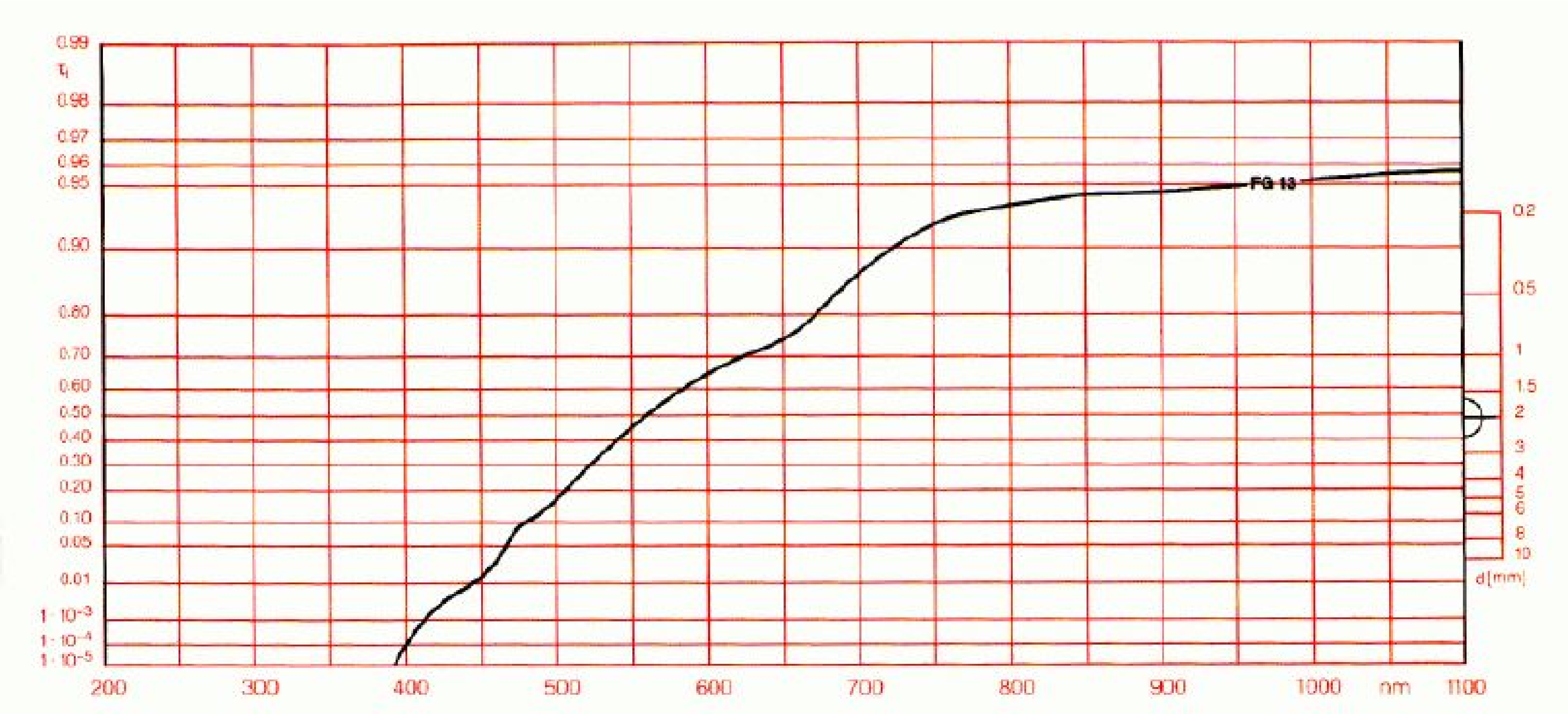
Schott series transmission curves for dyed-in-the-mass glass filters:



BG7; BG13

Appendix:

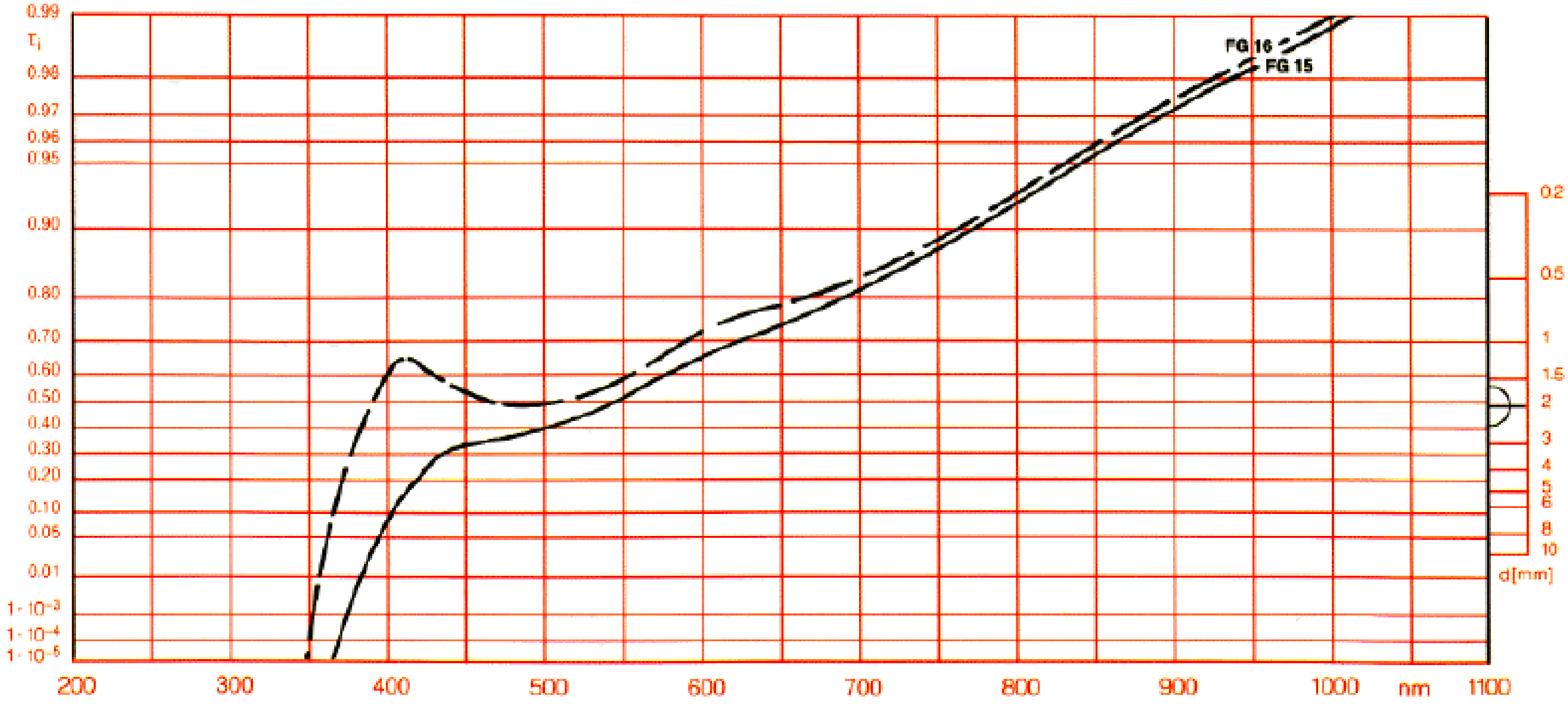
Schott series transmission curves for dyed-in-the-mass glass filters:



FG13

Appendix:

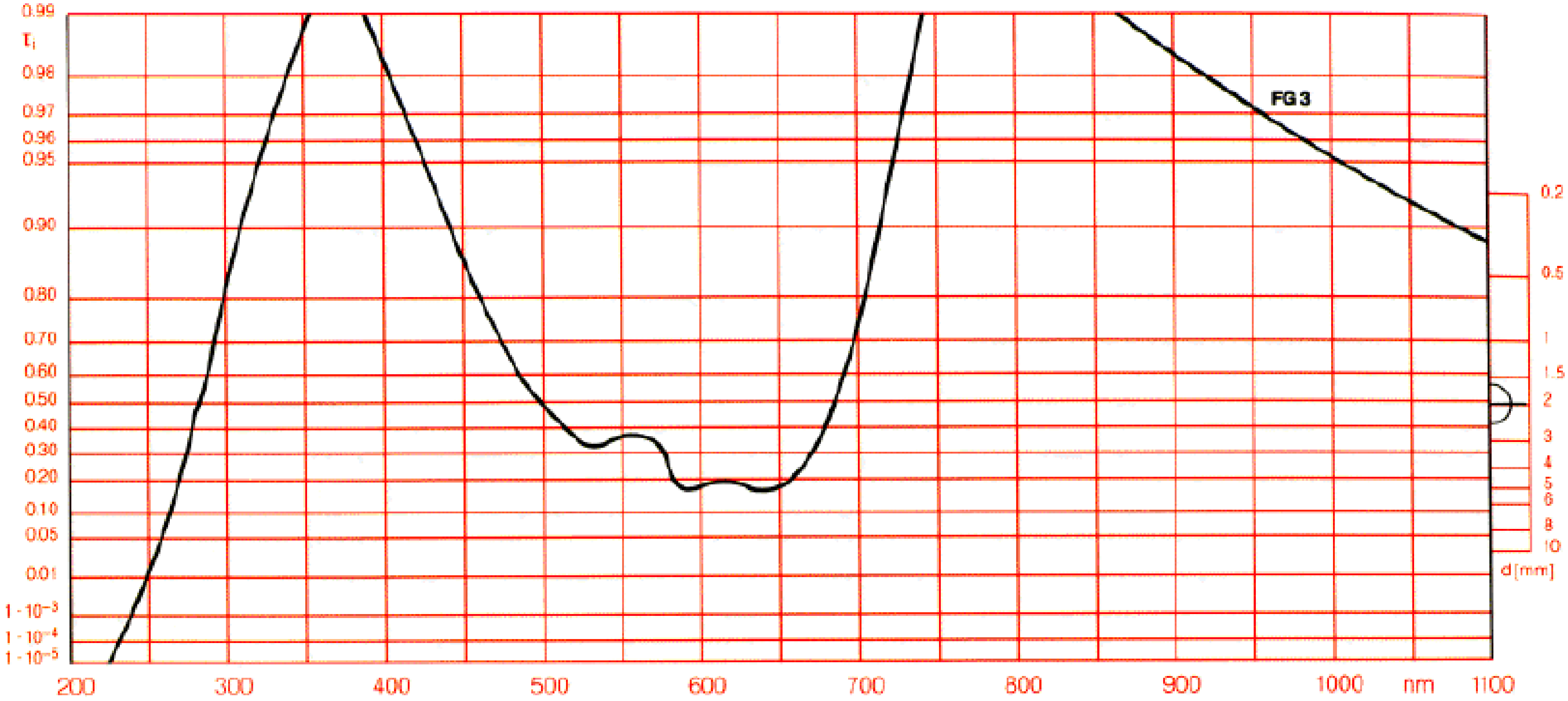
Schott series transmission curves for dyed-in-the-mass glass filters:



FG15; FG16

Appendix:

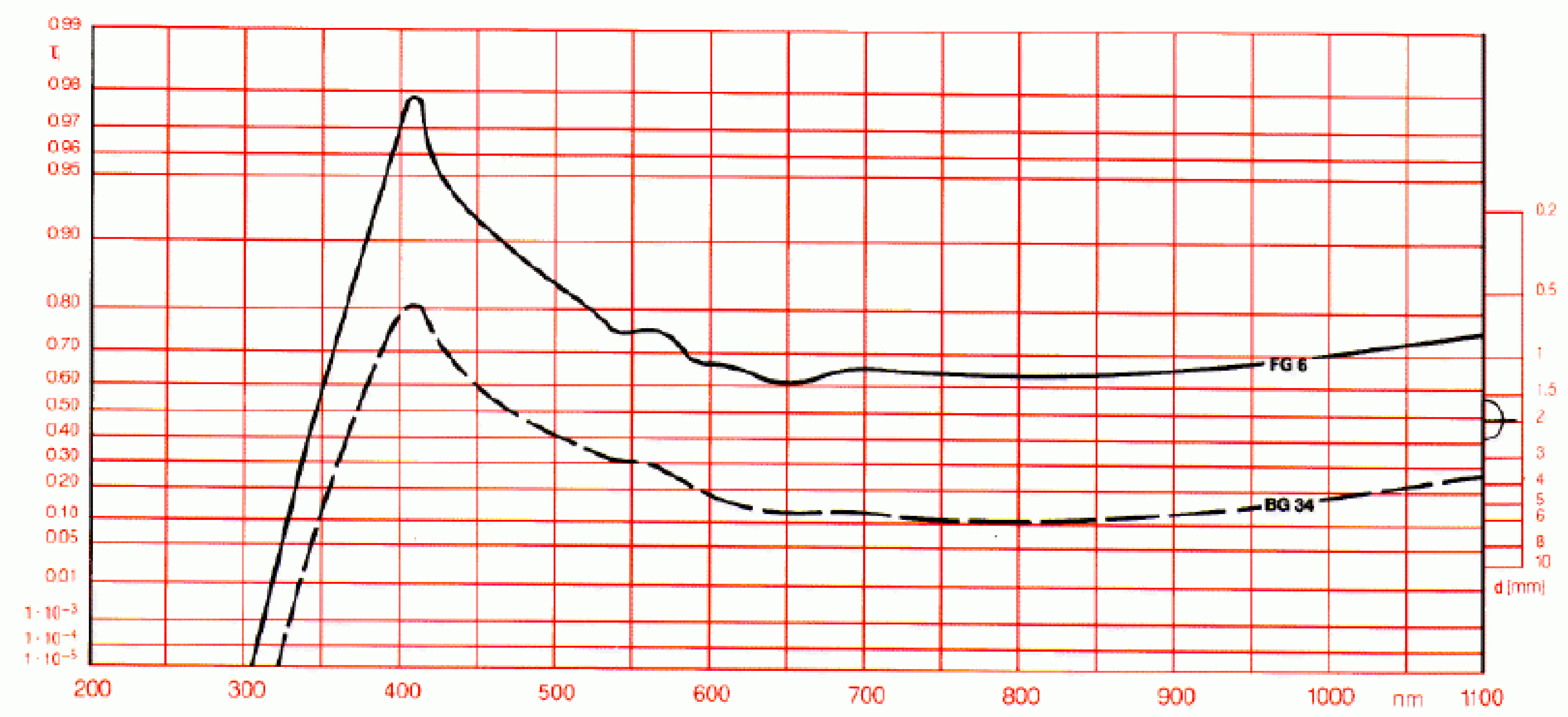
Schott series transmission curves for dyed-in-the-mass glass filters:



FG3

Appendix:

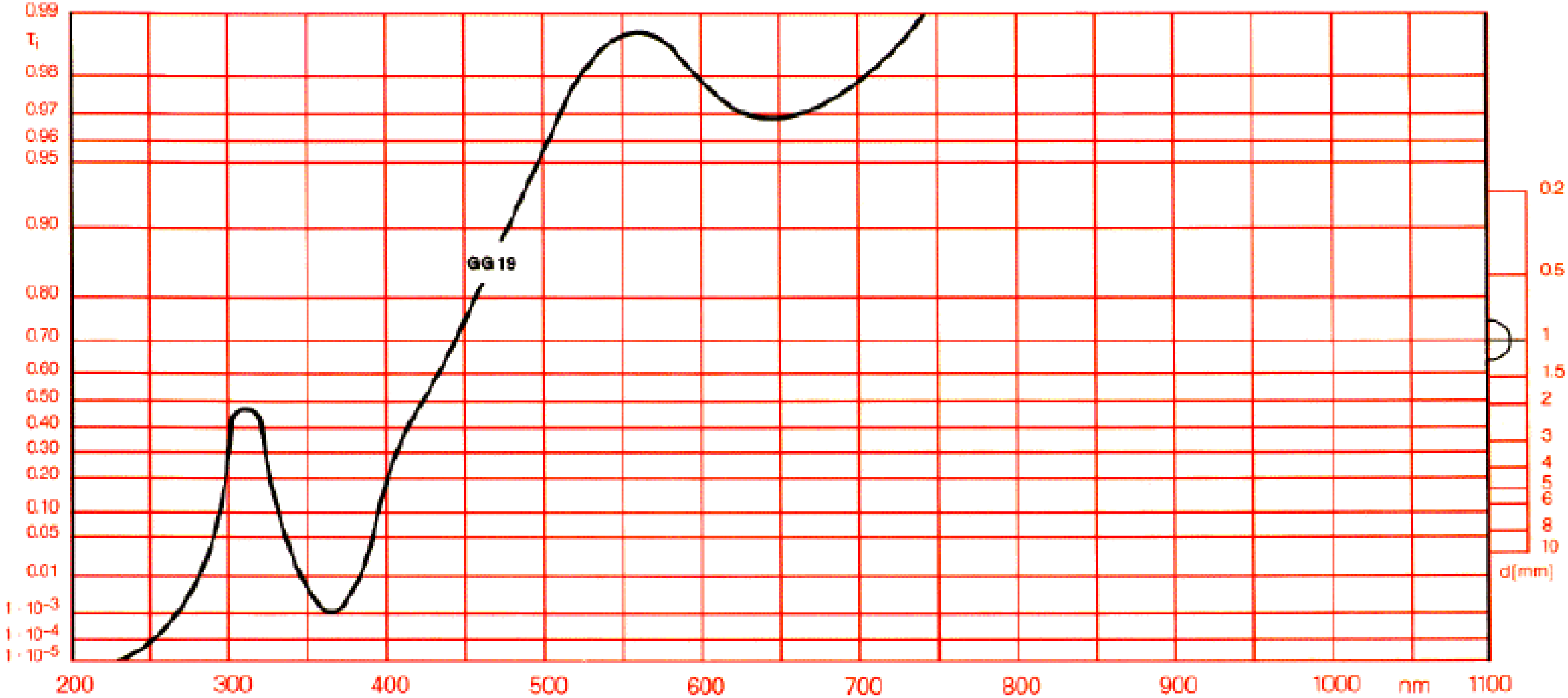
Schott series transmission curves for dyed-in-the-mass glass filters:



FG6; BG34

Appendix:

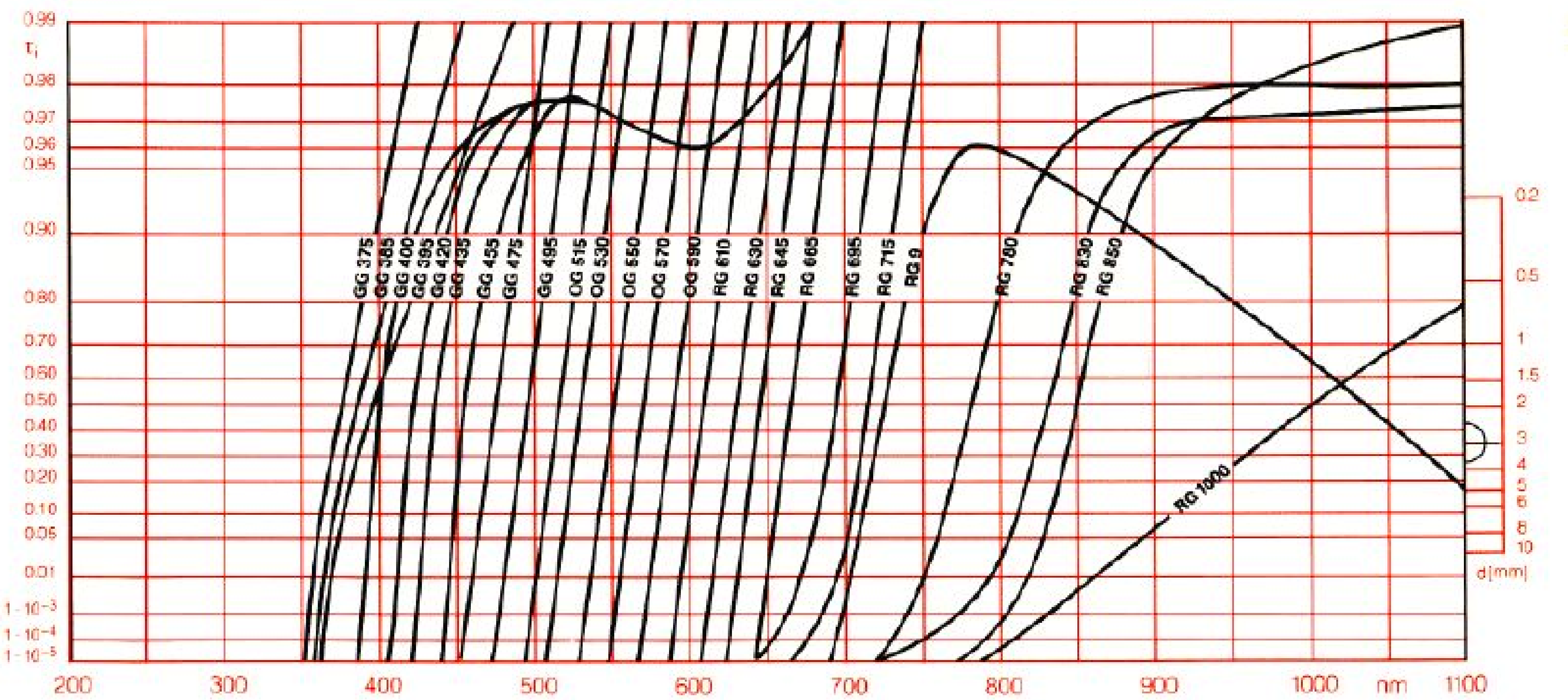
Schott series transmission curves for dyed-in-the-mass glass filters:



GG19

Appendix:

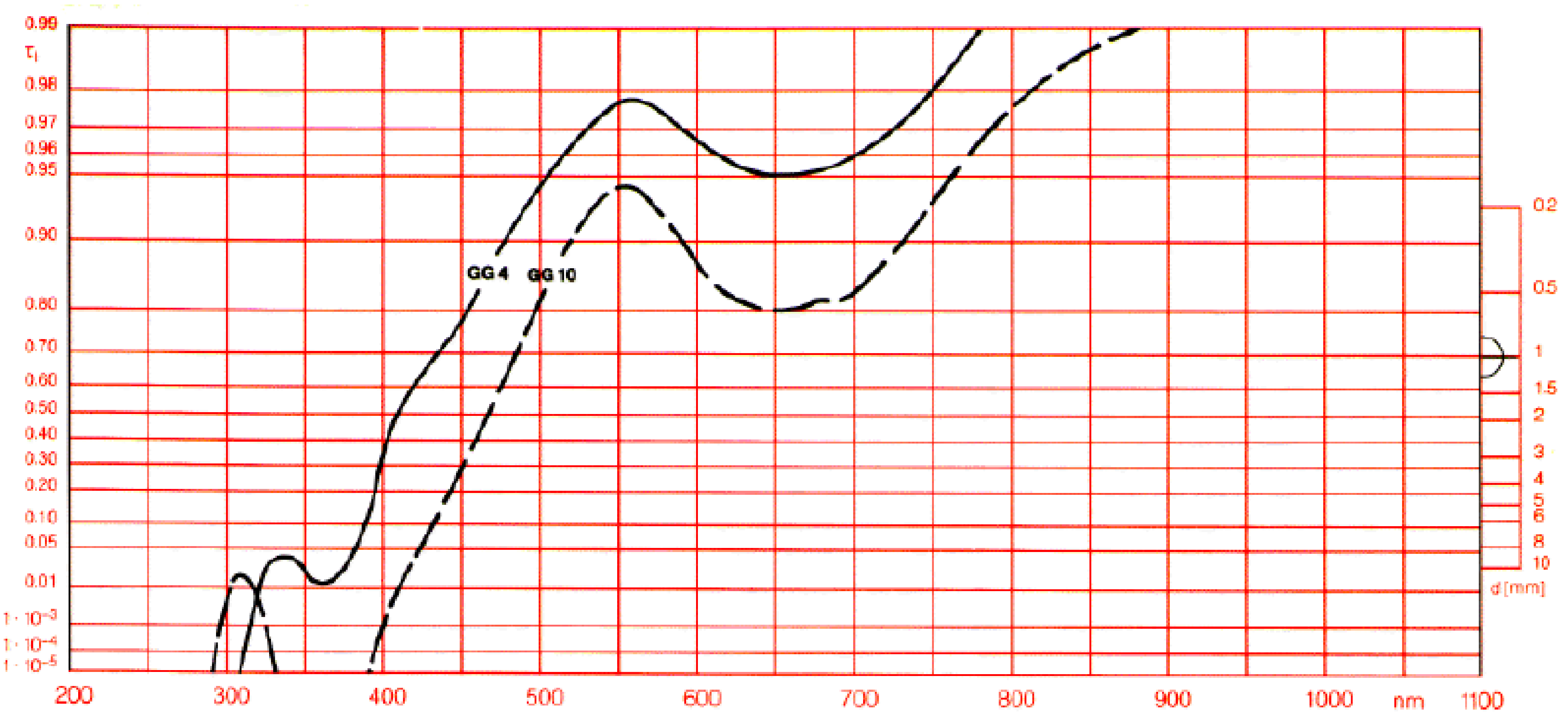
Schott series transmission curves for dyed-in-the-mass glass filters:



GG375 TO RG1000

Appendix:

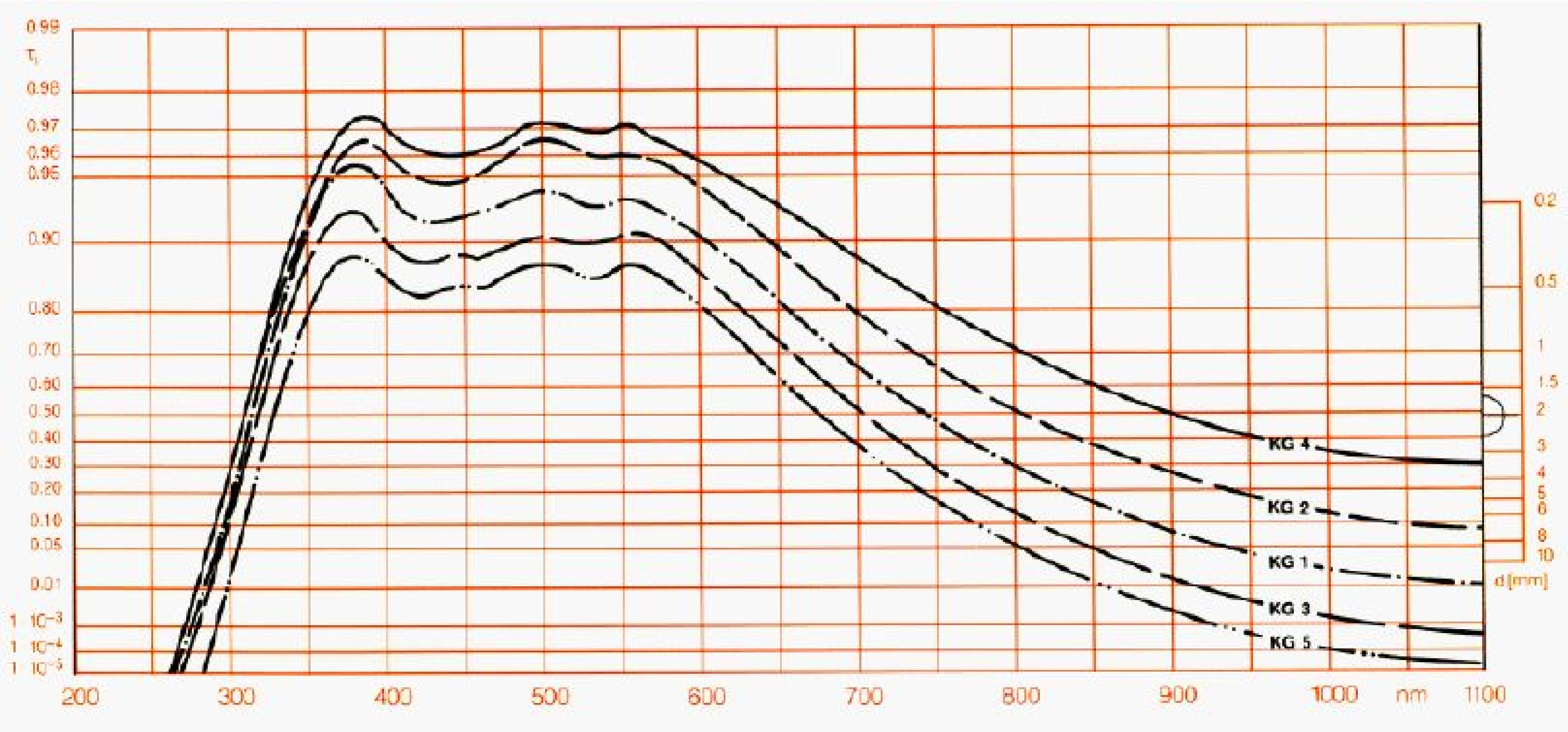
Schott series transmission curves for dyed-in-the-mass glass filters:



GG4; GG10

Appendix:

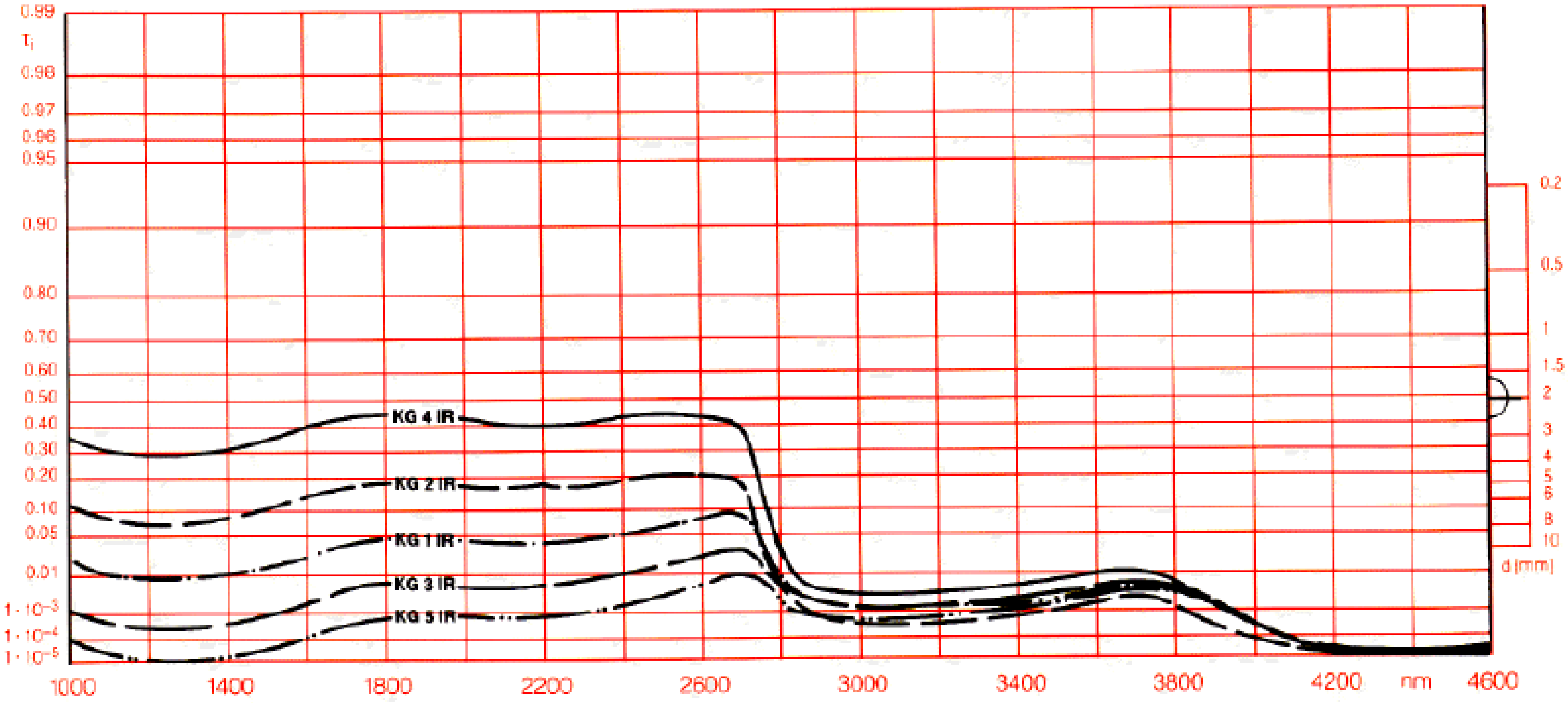
Schott series transmission curves for dyed-in-the-mass glass filters:



KG1 TO KG5

Appendix:

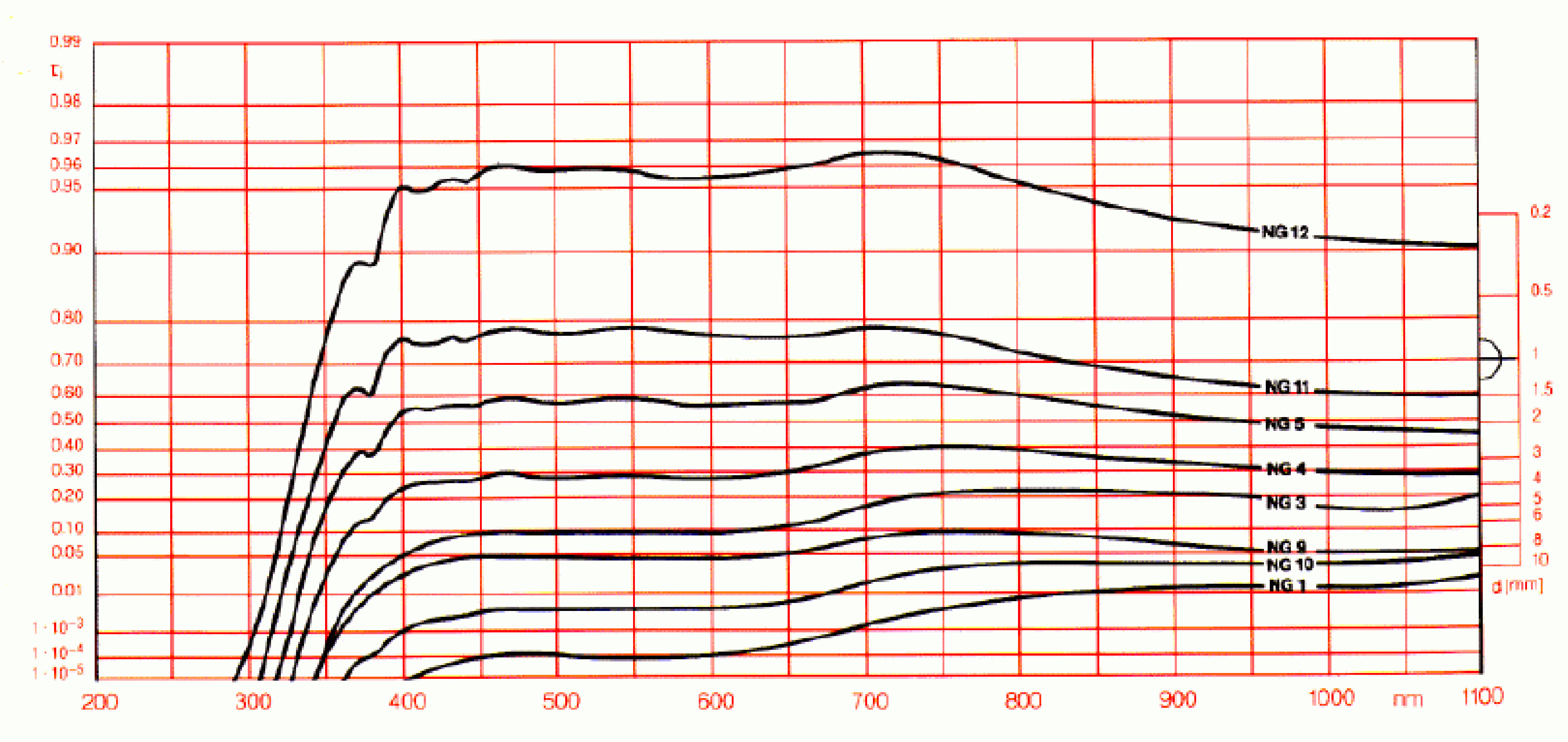
Schott series transmission curves for dyed-in-the-mass glass filters:



KG1IR TO KG5IR

Appendix:

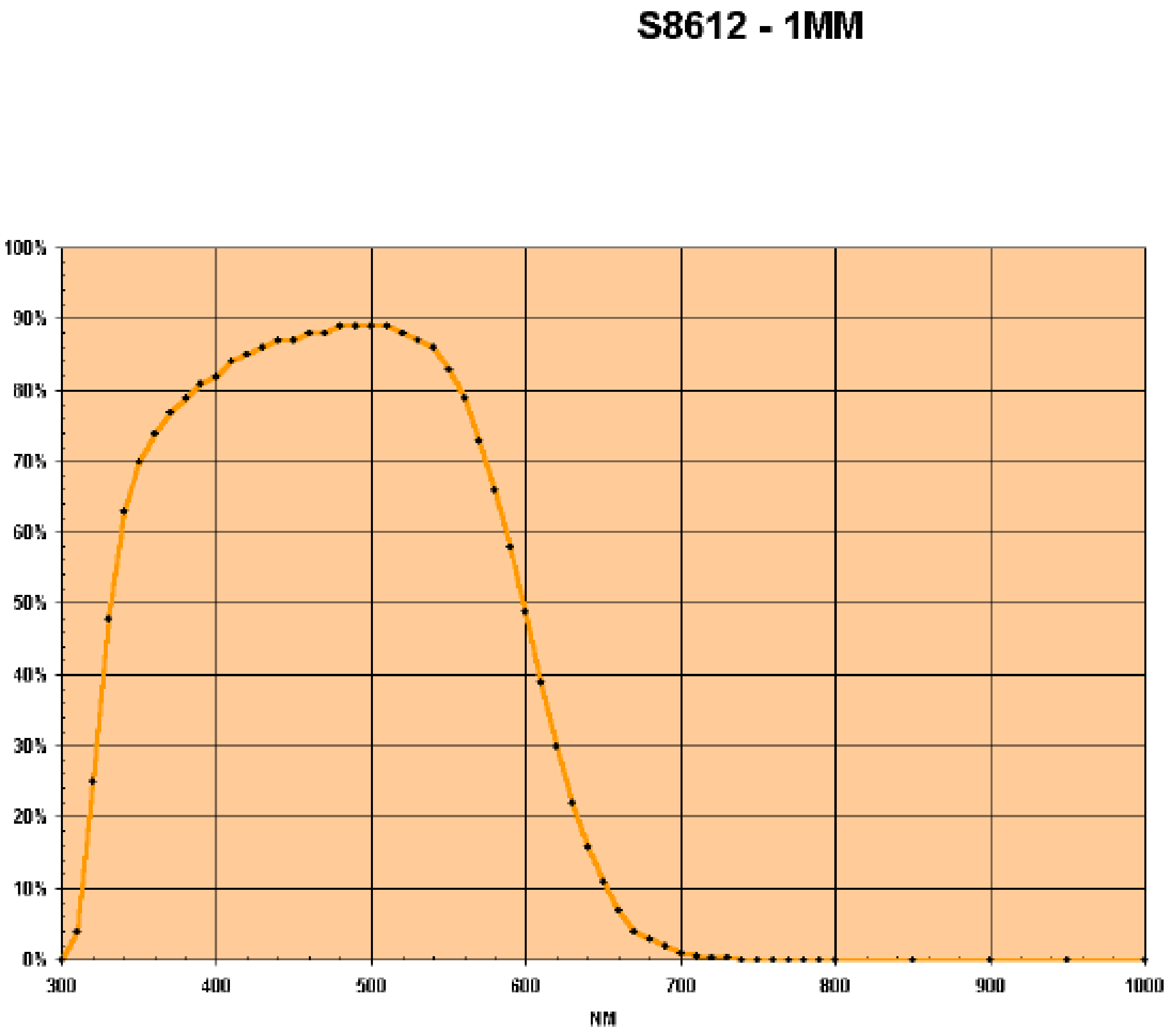
Schott series transmission curves for dyed-in-the-mass glass filters:



NG1; NG3; NG4; NG5; NG9; NG10; NG11; NG12

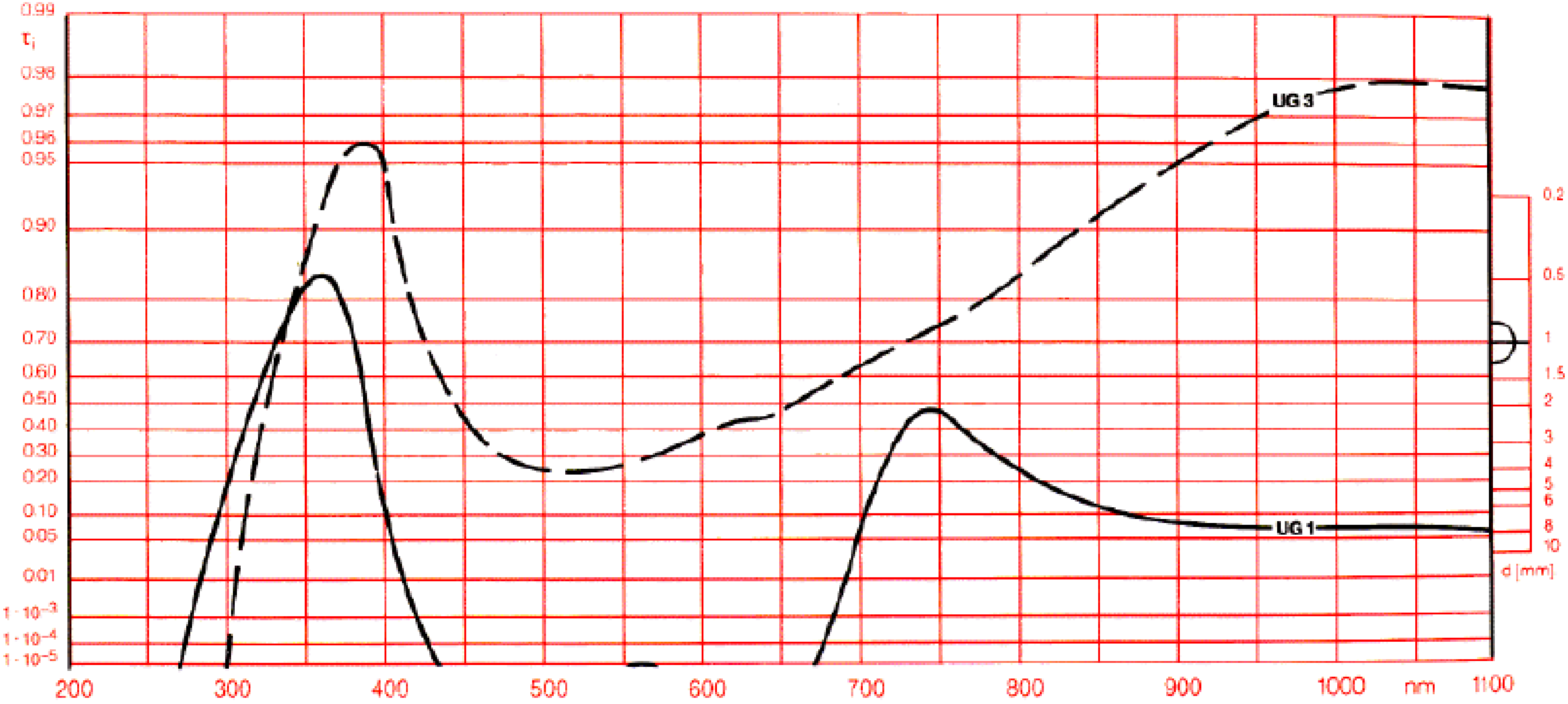
Appendix:

Schott series transmission curves for dyed-in-the-mass glass filters:



Appendix:

Schott series transmission curves for dyed-in-the-mass glass filters:



UG1; UG3

SCHOTT

TOTAL CUSTOMER CARE

UG 1

Reflection factor

P_d	0.91

Bubble content

Bubble class	1

Chemical resistance

FR class	0
SR class	1.0
AR class	1.0

Density

ρ [g/cm³]	2.77

Transformation temperature

Tg [°C]	603

Thermal expansion

$\alpha_{-30/+70°C}$ [10^{-6}/K]	7.9
$\alpha_{20/300°C}$ [10^{-6}/K]	8.9

Temperature coefficient

T_k [nm/°C]

Per DIN 58191 BP 351/78

Per DIN 58191

Ionically colored glass

Limit values of τ_i
for thickness d = 1 mm

Wave-length [nm]	Limits	Value from catalog curve
365	≥0.80	0.83
405	≤0.10	0.05
694	≤0.06	0.01
750	≤0.53	0.45

Refractive index n

λ [nm]	Element	n
365	Hg	1.57
587.6	He	1.54

Tristimulus values

	d [mm]	x	y	Y	λ_d [nm]	P_e
A	1					
2856	2					
K	3					
	5					
	1					
3200	2					
K	3					
	5					
	1					
D_{65}	2					
	3					
	5					

Application notes

Band pass filter
- see section 6.7.3

V
Transmission changes are possible under the action of intense ultraviolet radiation
- see section 8.3

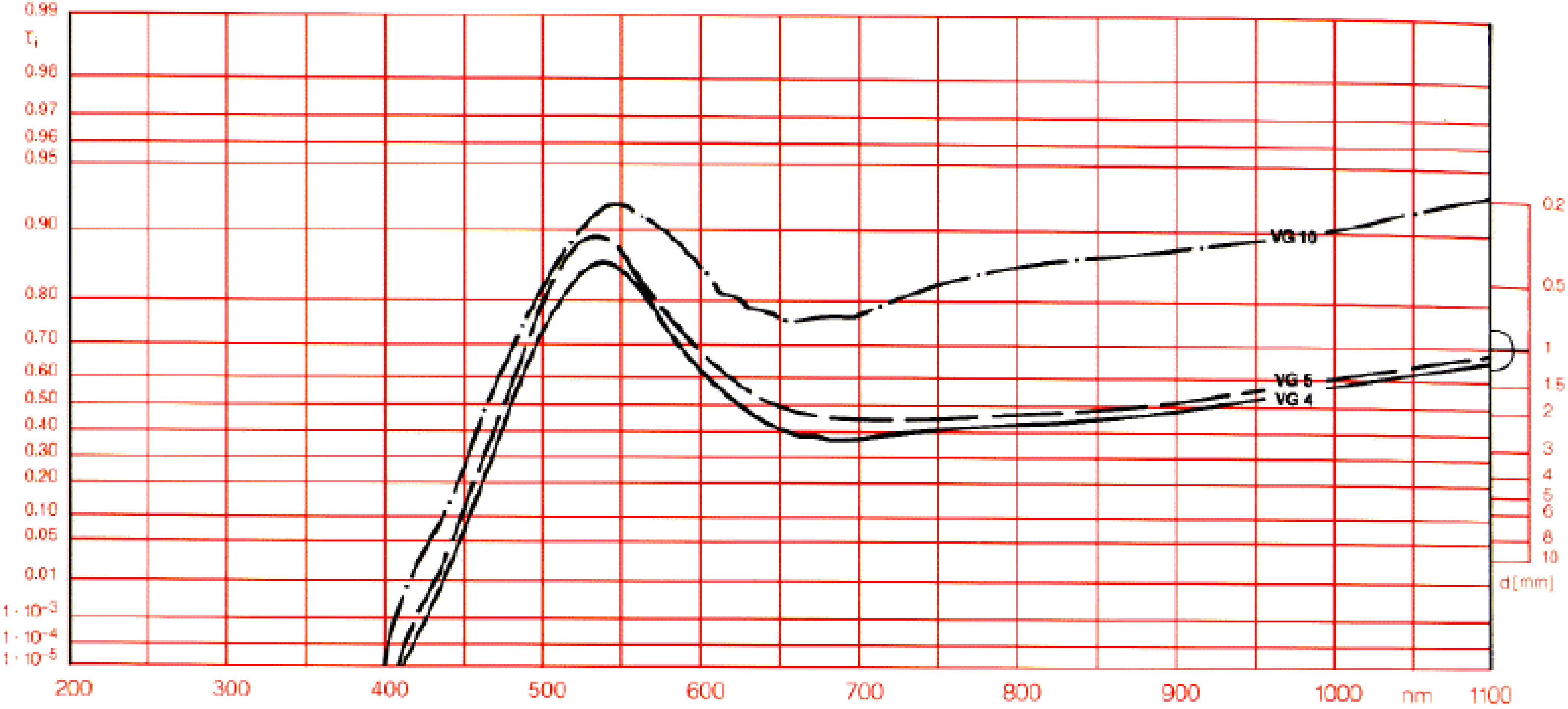
Status June 1997

Transmittance τ and internal transmittance τ_i at d = 1 mm

λ [nm]	τ	τ_i	λ [nm]	τ	τ_i
200	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	700	0.04	0.05
210	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	710	0.15	0.16
220	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	720	0.26	0.29
230	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	730	0.34	0.38
240	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	740	0.41	0.45
250	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	750	0.42	0.47
260	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	760	0.39	0.43
270	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	770	0.32	0.36
280	0.004	0.004	780	0.28	0.31
290	0.04	0.05	790	0.26	0.28
300	0.16	0.18	800	0.23	0.25
310	0.34	0.37	850	0.11	0.12
320	0.50	0.54	900	0.07	0.08
330	0.61	0.67	950	0.06	0.06
340	0.69	0.76	1000	0.06	0.06
350	0.74	0.81	1060	0.05	0.06
360	0.76	0.83	1100	0.04	0.05
370	0.74	0.81	1200	0.03	0.03
380	0.63	0.69	1300	0.03	0.03
390	0.38	0.42	1400	0.03	0.03
400	0.11	0.12	1500	0.03	0.03
410	0.01	0.01	1600	0.03	0.03
420	$6 \cdot 10^{-4}$	$6 \cdot 10^{-4}$	1700	0.03	0.03
430	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	1800	0.02	0.02
440	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	1900	0.02	0.02
450	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2000	0.04	0.04
460	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2100	0.05	0.05
470	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2200	0.06	0.07
480	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2300	0.08	0.09
490	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2400	0.11	0.12
500	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2500	0.13	0.14
510	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2600	0.15	0.16
520	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2700	0.16	0.18
530	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2800	0.11	0.12
540	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	2900	0.12	0.13
550	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	3000	0.13	0.14
560	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	3200	0.14	0.15
570	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	3400	0.15	0.17
580	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	3600	0.18	0.20
590	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	3800	0.22	0.24
600	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	4000	0.26	0.29
610	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	4200	0.27	0.30
620	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	4400	0.20	0.22
630	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	4600	0.07	0.08
640	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	4800	0.02	0.02
650	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	5000	0.005	0.006
660	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	5200	$6 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
670	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$			
680	$9 \cdot 10^{-5}$	$1 \cdot 10^{-4}$			
690	0.004	0.004			

Appendix:

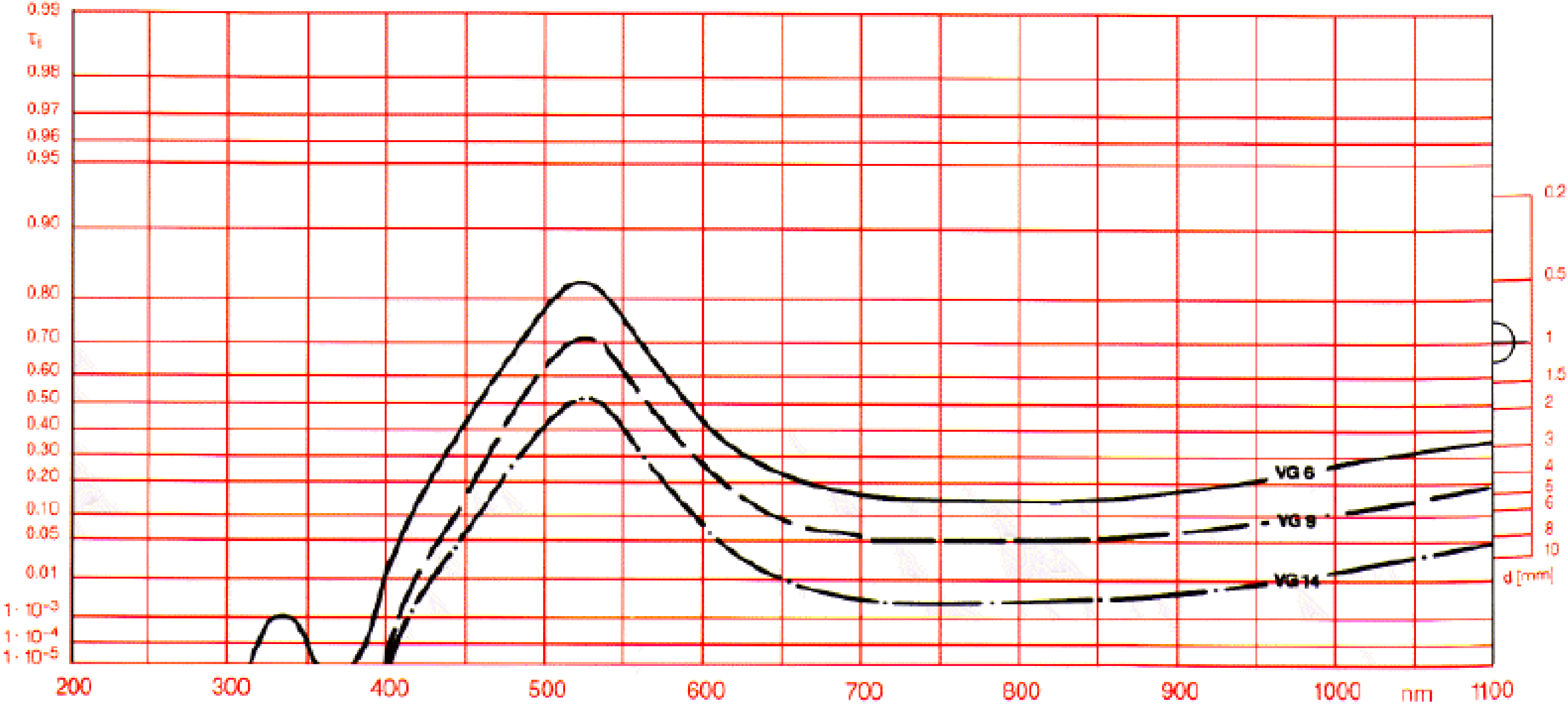
Schott series transmission curves for dyed-in-the-mass glass filters:



VG4; VG5; VG10

Appendix:

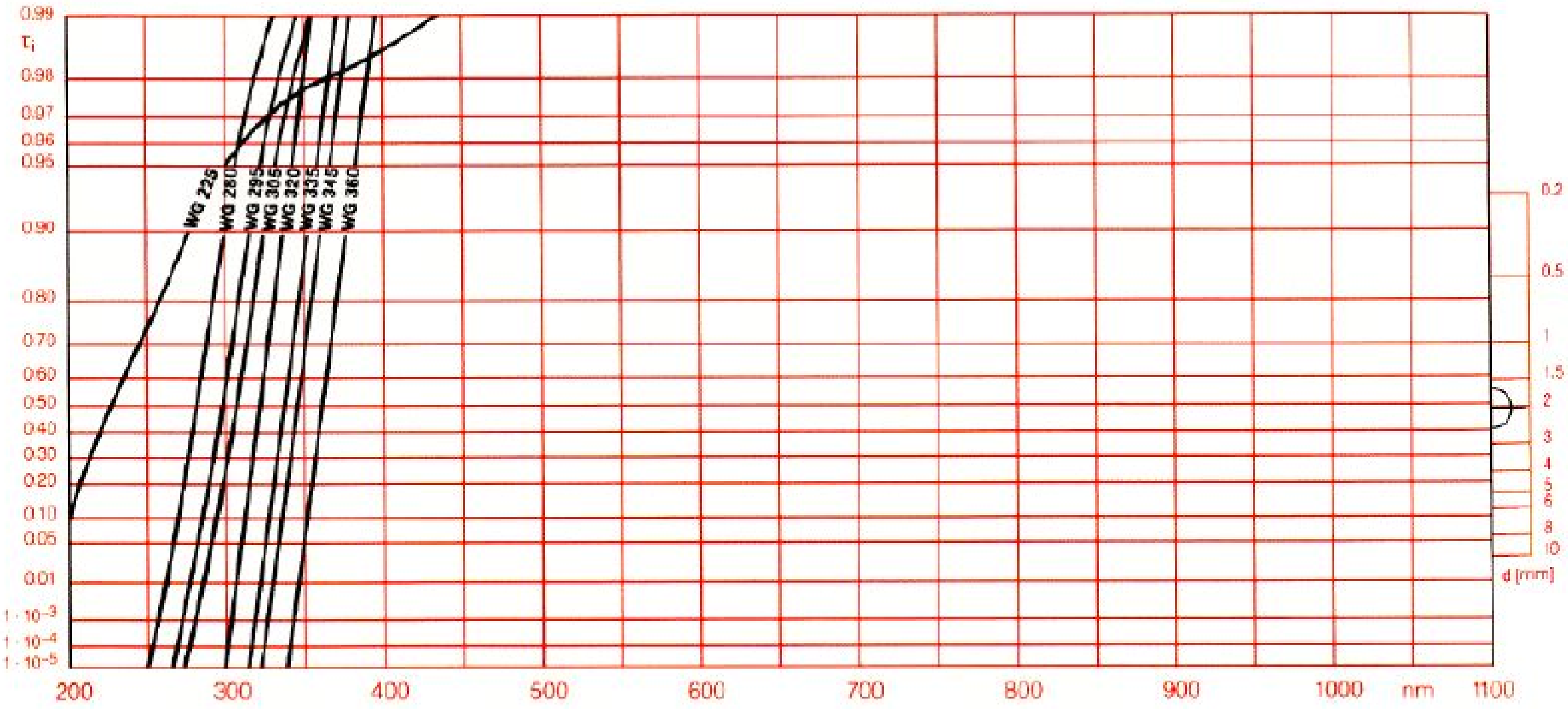
Schott series transmission curves for dyed-in-the-mass glass filters:



VG6; VG9; VG14

Appendix:

Schott series transmission curves for dyed-in-the-mass glass filters:



WG225; WG280; WG295; WG305 WG320; WG335; WG345;WG360