Exemption Renewal Request Form

Date of submission: 11 Nov 2014

1. **Name and contact details**

Name of applicant:

SPECTARIS

with support of:

AFOP - Le Syndicat Professionnel Optique Photonique

Communication and Information Network Association of Japan

DIGITALEUROPE

European Aluminium Association

European Copper Institute

European Passive Components Industry Association

European Semiconductor Industry Association

European Special Glass Association

Gesamtverband der Aluminiumindustrie

InformationTechology Industry Council

IPC – Association Connecting Electronics Industries

Japan Business Council in Europe

Japan Business Machine and Information System Industries Association

Japan Electronics and Information Technology Industries Association

LIGHTINGEUROPE

TechAmerica Europe

The Japan Electrical Manufacturers´ Association

Wirtschaftsvereinigung Metalle

Contact details of applicant:
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Function: Head of Photonics Division
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2. Reason for application:
Please indicate where relevant:

- Request for new exemption in:
- Request for amendment of existing exemption in
- Request for extension of existing exemption **13a in Annex III**
- Request for deletion of existing exemption in:
- Provision of information referring to an existing specific exemption in:
    - Annex III
    - Annex IV
- No. of exemption in Annex III or IV where applicable: **13a**
- Proposed or existing wording: **Lead in white glasses used for optical applications**
- Duration where applicable: **No expiry date**
- Other:

3. Summary of the exemption request renewal request
This exemption renewal request is for the use of lead in optical glass that is used in electrical and electronic equipment. Optical glass containing lead is used in a very wide variety of applications and in many types of equipment. Lead based glasses are used because they have unique combinations of properties and characteristics that cannot be achieved by lead-free optical glass or by different designs. As a result the technical requirements of the glass and the equipment in which it is used can only be achieved with lead-based optical glass.

4. Technical description of the exemption request / revocation request
(A) Description of the concerned application:
1. To which EEE is the exemption request/information relevant?
Name of applications or products:

Optical glass containing lead is used in many different types of EEE. There are too many examples of uses of lead-based optical glass to list and explain in detail here. More detailed descriptions of several example applications are described below in answers to other questions.
Illustrative examples are listed below:

- Lenses for professional photographic cameras (category 4) – these consist of multiple concave and convex lens elements, which are made with a variety of types of glass each having different but essential characteristics. These lenses need to be precisely designed to achieve the best optical performance
- Lenses for video and television cameras, camcorders, movie projectors and for photo-laboratory equipment (category 4) – these are even more complex than still camera lenses requiring more individual lenses. Lenses with 12 or more elements are not unusual. As there is a significant thickness of glass that light must pass, the transmission performance in the entire visible spectrum of all glass types used must be as high as possible.
- Cine photography (category 4) – Needs to use a variety of high-quality lenses. The characteristics, such as image quality and colour location of an individual lens of a given focal length must be taken into consideration, but unlike still

photography, the lens must be regarded as part of a batch of lenses of different focal lengths (prime and zoom lenses).
In cinema movies, a sequence will be cut into takes from different views and distances which is achieved by using lenses with different focal lengths. The observer's eye is very sensitive to colour changes (or as it is called in photography: colour or white balance) between different takes of the same scenery.

Figure 1. Pictures of a lily as shot with a digital camera (left) and with colour balance correctly adjusted to the illumination conditions (right) changing from a colder to a warmer perception (from Wikipedia "Colour balance").
If such changes in colour balance occur from one take to another of the same scenery, this would be very disturbing to the viewer.

One company's advertisements state that their lenses are colour matched to the other lenses in the same range, to guarantee seamless cuts between scenes and to avoid time-consuming colour matching in post." Many of these lenses need to use leaded glass.
In consequence, the distribution in both the image quality and the colour location of all of the lenses required within one batch must be reduced to a level where any differences are too small to be noticeable. The loss of one or two lenses (e.g. due to withdrawal of exemption 13a), depending on the quality of the focal lengths in a batch, could jeopardize the usability of an entire batch. This also relates to cases of replacements for irreparable lenses that are sold in batches (see additional information for explanation).

- Lenses for high performance binoculars and telescopes having electrical functions (category 4).
- Optical systems designed for telecom applications in the near IR spectral range from 1000 to 1500 nm (category 3)
- Digital projectors and rear projection televisions (category 4). Lead glass lenses and prisms are used because these are the only types of glass that have high % transmission at shorter wavelengths and do not cause distortion of the image when the glass temperature increases by heating from the intense light source. This is because the refractive index is less affected by temperature changes than lead-free glasses. Heating the glass also affects focusing of the image causing distortion but lead glass lenses can compensate to avoid distortion.
- Endoscopes used for inspection of engineered products (category 6 or 9)
- Medical endoscopes (category 8)
- Fibres for high quality illumination units for operation microscopes in microsurgery (category 8)
- Surgical microscopes (category 8)
- Professional ophthalmic instruments (category 8)

- Temperature compensated high end optical imaging systems for medical applications (category 8)
- Temperature compensated high end optical imaging systems for printing and photolithography applications used for industrial tools (category 6). More details on why lead glass is needed for photolithography are given below.
- Optics used in instruments ~~used~~ for applications and diagnosis in the near UV-region such as bio-fluorescence, gene analyses and print-scanners (categories 8 and 9)
- Spectrometers (visible and UV light) used for analysis and for environmental monitoring (category 9)
- Polarimeters are used to characterize the optical activity of substances. This is for example important for enantiomeric purity control of pharmaceutical substances to prevent harmful secondary effects of enantiomeric contaminations like in the Contergan-scandal from 1957 to 1962. A central element of polarimeters are Faraday modulators containing glass rods which excel via their ability to rotate the polarization plane of linear polarized light when a magnetic field is applied. These glass rods must have a high optical dispersion (Verdet-constant) to fulfil their function. High dispersion can only be obtained by adding lead to the glass formulation. To date, there is no alternative to lead in high-dispersive glasses.
- Optics for laser surgery (category 8)
- Colour correction lenses used for most of the above applications. These correct for colour aberration (see Q 4A3 below), eliminate stray light and unwanted reflections to achieve the best possible image quality.
- Relay lens – these are used to invert images and are used in periscopes, endoscopes, telescopes, microscopes, etc.
- CNC video measuring systems, which are used to measure the dimensions of very small objects such as engineered parts such as for aircraft, e.g. precision made fuel valves and small watch components, silicon wafers for semiconductor and MEMS devices. These use high brightness lamps with prisms and lenses which need to have a high internal transmittance at all visible wavelengths and a very low (near zero) photoelastic constant (β) to avoid distortion that would give less accurate measurements. The optical properties of the glass must be affected by temperature ~~by~~ as little as possible (i.e. low birefringence) and the glass should have a high thermal conductivity to avoid distortion due to temperature gradients in the lens or prism (category 9).
- Light guides and lenses for optical microscopes, endoscopes and in IVD equipment. Lead in the glass is needed for high % transmittance at shorter wavelengths, high refractive index and as it has the anomalous dispersion properties required for chromatic aberration compensation. Lead-glass light guides are also used for other applications. Microscopes are used for many different areas of technology (category 8 and 9) – see more detailed description below.
- Optical telecommunications lenses, such as in optical transceivers, light collimation, optical amplifiers, switches, isolators and transponders (category 3)
- Laser optics for commercial printers. Large cylindrical lenses are used which must be lead-glass for optimum temperature stabilisation
- Aspherical lenses
- Lead-glass may also be used in many other types of equipment, such as lighting applications (crystal glass which may be used in lighting applications is covered by exemption 29), toys and leisure products and automatic dispensers (e.g. ATM (Automatic Teller Machine) machines).

Optical microscope applications: The following are examples of uses of optical microscopy: These include a number of applications in research and routine microscopy, as well as in the bio-medical and industrial field relying on high or at least reasonable transmission in the near-UV spectral range. Examples are:

- Confocal microscopy is a type of fluorescence microscopy with a special emphasis on the 405 nm excitation wavelength which can be efficiently used in order to excite fluorescent markers. Also this ‘relatively’ short wavelength is used for confocal material science and topography as the spatial resolution increases with lower wavelength. Lead-based glass must be used to achieve high transmission at the 405nm wavelength.
- Laser micro dissection crucially depends on UV lasers (355 nm) in order to cut and separate cells and tissue. Specially designed microscopes are used in which the laser beam that is used to separate and then remove individual cells passes through the microscope lenses that are also used to view the cells. High light transmission is needed at all wavelengths to be able to see individual cells as well as for high transmission at the UV laser’s wavelength of 355nm. At this short wavelength, only lead-based glass has high percentage of light transmission and all other essential characteristics, as described below.
- Fluorescence microscopy as a standard research and routine analysis tool depends on high or at least ‘reasonable’ transmittance in the near-UV range. Specific examples are
    - Ratio imaging with fluorophores (fluorescent dye) such as FURA (an aminopolycarboxylic acid) that can be exited at 340 nm and 380 nm and are routinely used to monitor intracellular Ca^{2+} concentration and cellular regulation. This fluorophore was developed by R. Tsien who was awarded the Nobel prize in chemistry 2008 and the method is cited in thousands of scientific publications. This technique is also used in the study of Parkinson’s disease, Myocardiocyten Stroke and Epilepsy[1] by measurement of the ratio of the emissions at different wavelengths as this is directly correlated to the amount of intracellular calcium.
    - “Fluorescence Recovery After Photobleaching” (FRAP) denotes an optical technique capable of quantifying the two dimensional lateral diffusion of a molecularly thin film containing fluorescently labelled probes, or to examine single cells. This technique is very useful in biological studies of cell membrane diffusion and protein binding.
    - The use of 4',6-diamidino-2-phenylindole (DAPI) as a fluorescent stain that binds strongly to A-T rich regions in DNA and is a standard marker in immunofluorescence. [2]

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[1] The role of calcium and mitochondrial oxidant stress in the loss of substantia nigra pars compacta dopaminergic neurons in Parkinson's disease. Neuroscience. 2011 Dec 15;198:221-31. doi: 10.1016/j.neuroscience.2011.08.045. Epub 2011 Aug 25. Review. Schreckenberg R, Dyukova E, Sitdikova G, Abdallah Y, Schlüter KD. Mechanisms by which calcium receptor stimulation modifies electromechanical coupling in isolated ventricular cardiomyocytes. Pflugers Arch. 2014 Apr 1. Maroto M, de Diego AM, Albiñana E, Fernandez-Morales JC, Caricati-Neto A, Jurkiewicz A, Yáñez M, Rodriguez-Franco MI, Conde S, Arce MP, Hernández-Guijo JM, García AG.Multi-target novel neuroprotective compound ITH33/IQM9.21 inhibits calcium entry, calcium signals and exocytosis. Cell Calcium. 2011 Oct;50(4):359-69. doi: 10.1016/j.ceca.2011.06.006. Epub 2011 Aug 11. Sun DA1, Sombati S, Blair RE, DeLorenzo RJ. Calcium-dependent epileptogenesis in an in vitro model of stroke-induced "epilepsy". Epilepsia. 2002 Nov;43(11):1296-305.

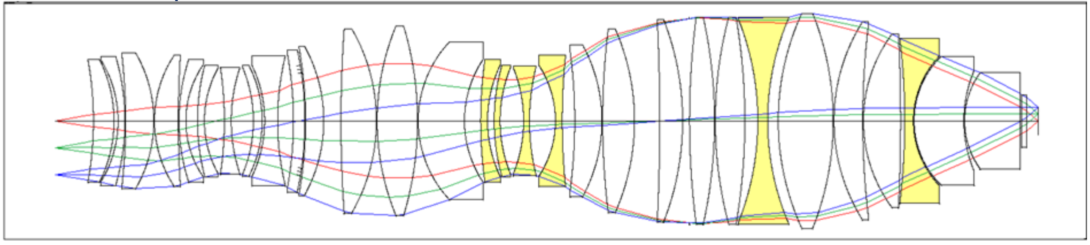
[2] Cancer: Stoehr, R., P. Wild, et al. (2003). "Lasermicrodissection – An important prerequisite for the molecular-genetic analysis of bladder cancer." Pathol Res Pract 199: 355-362. Alzheimer’s R&D Chadi, G., J. R. Maximino, et al. (2009). "The importance of molecular histology to study glial influence on

- Total Internal Reflection Fluorescence (TIRF) microscopy as a tool that is used to achieve sub-diffraction-limited axial resolution.
- Laser capture micro dissection is used for the identification and isolation of cells from larger tissue microenvironments and is used for research into Cancer and Alzheimer's disease. This technique requires high % transmission at 348 and at 355nm
- Parkinson's disease, Epilepsy and Depression are studied using light of 350 – 530nm by activation of proteins using stimulating light sources[3].

All these microscopy methods have a significant impact on the European research landscape covering research on cancer, AIDS, Alzheimer, as well as routine diagnostics like fluorescence-in-situ-hybridization, pathology, and digital slides. Dispensing lead-containing glasses would hence severely harm the academic research as well as pharmaceutical R&D in the European Union. Furthermore clinical analytics would become equally hindered with unpredictable consequences to the EU health system.

Recent innovations that have been possible only by using the highest performance optical microscopes that contain lead-glass lenses include:
- Research into cancer therapy to visualise Glioblastoma malignant brain tumours[4].
- Optical microscopes with lead-glass lenses were used to image mouse brain cells in research into brain functions[5].
- High performance optical microscopes are used to develop new bio-printing of 3D tissue structures that aim eventually to create human tissue that can be used for new drug testing[6].

Photolithography: Photolithography uses light with wavelength of 365nm to create the image and so high percentage of light transmission is needed at this wavelength. Lead-free glass absorbs a higher percentage of light and as the light output from the lamp cannot be increased, this significantly reduces productivity (i.e. less silicon wafers or images per hour).
The UV lamps used for photolithography are relatively hot and so local heating of the optical lenses can occur which would induce changes in refractive index which causes distortion so that fine structure cannot be imaged. However, lens heating also occurs due to light absorption and so when lead-free glass is used with higher light absorption at UV wavelengths, this absorbed light is converted into heat. As a result, lead-free glass will be heated more than lead-free lenses. The lenses of i-line lithography equipment include many different lenses to achieve the desired quality and an example is shown below:



neurodegenerative disorders. Focus on recent developed single cell laser microdissection." J Mol Histol 40(3): 241-250.

[3] 7 Tye K. M., Deissenroth, K., Optogenetic investigation of neural circuits underlying brain disease in animal models. Nature Neurosci.13, 251-266 (2012).

[4] http://www.youtube.com/watch?v=5QwwtxpNgEA&feature=youtu.be

[5] http://www.nytimes.com/2014/02/25/science/the-brains-inner-language.html?_r=1

[6] http://wyss.harvard.edu/viewpressrelease/141/

Figure 2 Lens design of a typical lithographic system

The use of exclusively lead-free optical glass will significantly reduce UV light transmission and much more light absorption than with leaded glass causing distortion due to lens heating. Lens heating can be avoided with lead-free glass only by using lower intensity lamps, which will reduce productivity by as much as seven-fold (a reduction of 85%, to about one seventh). This is totally impractical and would make EU industry uncompetitive and moreover, even at this low production rate, image quality is inferior and unsuitable for the finest line-width technology. Therefore glass types that have high transmission percentage at all wavelengths that do not cause distortion due to lens heating are needed and this limits the choices to lead-based optical glasses.

a. List of relevant categories: (mark more than one where applicable)

1	Yes	7	Yes
2	Yes	8	Yes
3	Yes	9	Yes
4	Yes	10	Yes
5	Yes	11	Yes
6	Yes		

b. Please specify if application is in use in other categories to which the exemption request does not refer:

c. Please specify for equipment of category 8 and 9:
The requested exemption will be applied in

- monitoring and control instruments in industry YES
- in-vitro diagnostics YES
- other medical devices or other monitoring and control instruments than those in industry YES

2. Which of the six substances is in use in the application/product?
(Indicate more than one where applicable)
Lead (Pb)

3. Function of the substance:
Glasses are usually transparent solid materials that can be made with many different compositions. Glasses are traditionally known as clear non-crystalline inorganic materials based on silicates that are used for windows, drinking vessels and decorative objects. Glasses are also used for optical components such as lenses, which are used in cameras, microscopes, projectors and many other different applications. The composition of glasses is very varied and this is controlled to achieve the desired combination of properties. For most technical applications, it is necessary that the glass has a combination of several specific characteristics. Traditional inorganic soda glasses that are used for windows in buildings are relatively inert and so remain transparent for hundreds of years, but these are not suitable for all optical applications. Various additives are used to control the combination of properties that is required for each application and colourless transparent glasses may contain, apart from sodium and silica, also potassium, boron (e.g. boro-silicate glasses), arsenic, antimony, calcium, barium and lead. Some amorphous (non-crystalline) polymeric materials that are hard and optically transparent are referred to as “glass polymers” and have unique combinations of properties, although these are different to traditional silicate based glasses.
Each ingredient in a glass is added to achieve specific combinations of properties although each individual optical property, such as high refractive index, can be

obtained by several different glass formulations. There are however, certain combinations of optical properties which can be achieved by only one or a few formulations and some combinations of characteristics are only possible in glass formulations that contain lead. Lead based glass has disadvantages such as higher density, which makes the optics heavier and it is softer than lead-free glass and so it is more easily scratched. However, the combination of optical properties cannot be achieved by any lead-free glass.

Lead is added to types of optical glasses that are used in a wide variety of electrical equipment to achieve the following characteristics, usually more than one of these properties are needed for a specific application and often many are necessary:

- **Medium to high refractive index** – important for optics used in microscopes, camera lenses, etc.
- **Specific Abbe number** – Abbe number is a measure of the variation of refractive index with wavelength so that the refractive index of a glass with a low Abbe number varies across the visible spectrum less than a glass with a high Abbe number. Lead based glasses can be formulated to have low Abbe numbers which reduces chromatic aberration (see below) in parallel to having a high refractive index in such lead based glasses. It is important to be able to control Abbe number so that by using combinations of lenses of different materials with different characteristics, very precise optical effects can be obtained. Professional camera lenses and microscope include several lenses made of several different glass formulations to achieve the required high performance.
- **Colour aberration** – There are two types of colour aberration that are affected by glass composition; lateral and axial. Axial chromatic aberration is due to differences in focal length of different colours whereas lateral chromatic aberration is affected by image size. Axial chromatic aberration is resolved by combining lenses of two different types of glass, one having a larger refractive index than the other. High refractive index lenses are made of lead-based glass for the best optical quality. Chromatic aberration occurs because all optical glasses that are used for lenses have a refractive index that varies with the wavelength of transmitted light (this property is related to the Abbe number). As a result, each colour focuses at a different convergence point, so that colour images appear with coloured fringes and this effect is more pronounced with high refractive index materials.
- **Transmission of light with a high proportion of blue / indigo / violet light** – most types of lead-free glasses tend to absorb a high proportion of light having shorter wavelengths (<450 nm) whereas lead-based glasses transmit a high proportion of short wavelength visible light to achieve accurate colour reproduction which is important for many applications (more details below).
- **Low stress birefringence (low stress optical constant)** – birefringence is a property of transparent materials where light travelling in one axis is refracted differently to light travelling in an axis at 90˚ to the other axis and this is due to the material having different refractive indices in perpendicular directions. Some types of calcite crystals (e.g. “Iceland Spar”) clearly show this effect; if a crystal is placed onto a printed page, two distinct images can be seen, one being shifted sideways from the other. Clear plastics such as polycarbonate and acrylics are very susceptible to birefringence and this can be seen as rainbow colours when the plastic items are stressed when viewed by polarised light (each wavelength is refracted differently so that incident white light is transmitted as separated colours).
- **Partial dispersion** – Glasses having identical refractive index and Abbe number can have different partial dispersion properties and this can

significantly affect image quality. Modulation transfer function (MTF) of a lens is a measure of image quality where a MTF of 1 is perfect quality with no loss of contrast (see additional information for a more detailed explanation of why partial dispersion is an essential criterion).

- **Achromatism** - see additional information
- **Petzval number** - see additional information
- **Abnormal dispersion** – this is a quality used to compensate for chromatic aberration.
- **Low photoelastic constant (β)** – important to minimise distortion due to birefringence when stress is imposed on the glass optics. Related to low stress birefringence, described above.
- **Press moulding characteristics** – aspherical lenses are made by forming in moulds before grinding and polishing. The moulded shape needs to be as close to the required dimensions as possible to minimise grinding wastes and this is easier with leaded glass because the melting temperature is lower than with lead-free glasses. This has a positive effect by using less energy in such press moulding processes due to up to the 200˚C lower process temperature.
- **Thermal properties** – Some optical systems require the use of two lens elements that are cemented together (cemented doublets). It is important that both lenses have similar thermal coefficient of expansion to allow for any temperature changes. This is sometimes impossible without lead-based optical glass. Some lens systems are required to maintain focus when the temperature changes (such as due to hot lamps) and this is sometimes possible only with lead-based glass.
- **Ionising radiation resistance and blocking** – Lead has a high atomic weight and density so is very effective as a barrier to ionising radiation. Such optical systems are used in equipment utilising or measuring ionising radiation. The use of lead as shielding for ionising radiation is however covered by RoHS exemption 5 of Annex IV.

Combinations of essential properties

As stated above, applications usually need many of the above characteristics. Some examples need a combination of high refractive index, a high percentage of short wavelength light transmission and low stress birefringence and these are all achievable only with optical glasses containing lead. Lead-free glass types are available which exhibit one or two of these properties only, but none exhibit all three. A few examples are described below.

Refractive index and Abbe number

The chart below shows the full range of glasses manufactured by Schott who are the only optical glass manufacturer in Europe. Marked on the chart are glasses that contain lead. Note that these include glasses with both low Abbe number and high refractive index.

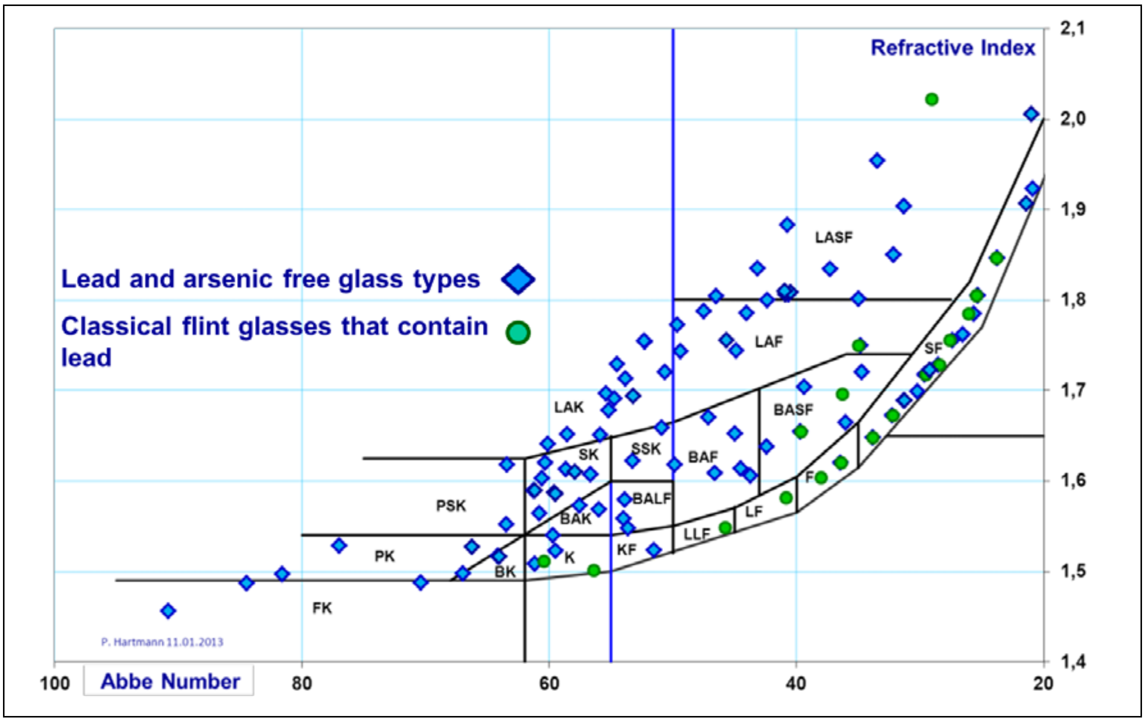


Figure 3. Chart showing Schott's range of optical glass.

Figure 3 shows several types of optical glass with high refractive index and low Abbe number. There are a few lead-free glasses with high refractive index and low Abbe number, but their other properties are different to the lead-based glasses and so are not always suitable as substitutes. Figure 3 shows that for most values of refractive index values, the lead-based glasses have the lowest Abbe number; the lead-based glasses mainly being at the right hand edge of the spread of results.

There is a vast amount of different optical systems each with a manifold of requirements. Present day applications can amount up to 40 or more functional requirements which have to be met simultaneously (hence the need for the large number of glass types shown in figure 3). Requirements are e.g. focal length or focal length range for zoom lenses, aperture, image resolution (MTF at all focal lengths), colour trueness, high contrast, high overall transmission, field flatness (sharp image over the total area of the flat sensor chip), low intrinsic fluorescence with many of them subdividing in detailed requirements on the different types of aberration effects (monochromatic and colour aberrations).
This means optimization of 40 or more parameters within one design. On the other hand there are not many degrees of freedom than can be adjusted in order to achieve the overall optimum. With optical systems they are: lens curvatures, thicknesses, inter-lens distances and lens materials i.e. optical glass types. So in general optical designers would need hundreds of glass types to enable their designs. This is in contradiction with the economy of glass supply, which would tend to strong reduction of the number of glass types. The offered range of glass types is a compromise which is continuously challenged from both sides.

High percentage of light transmission at shorter wavelengths

Figure 4 below shows the light transmission percentage curve of five examples of glasses:

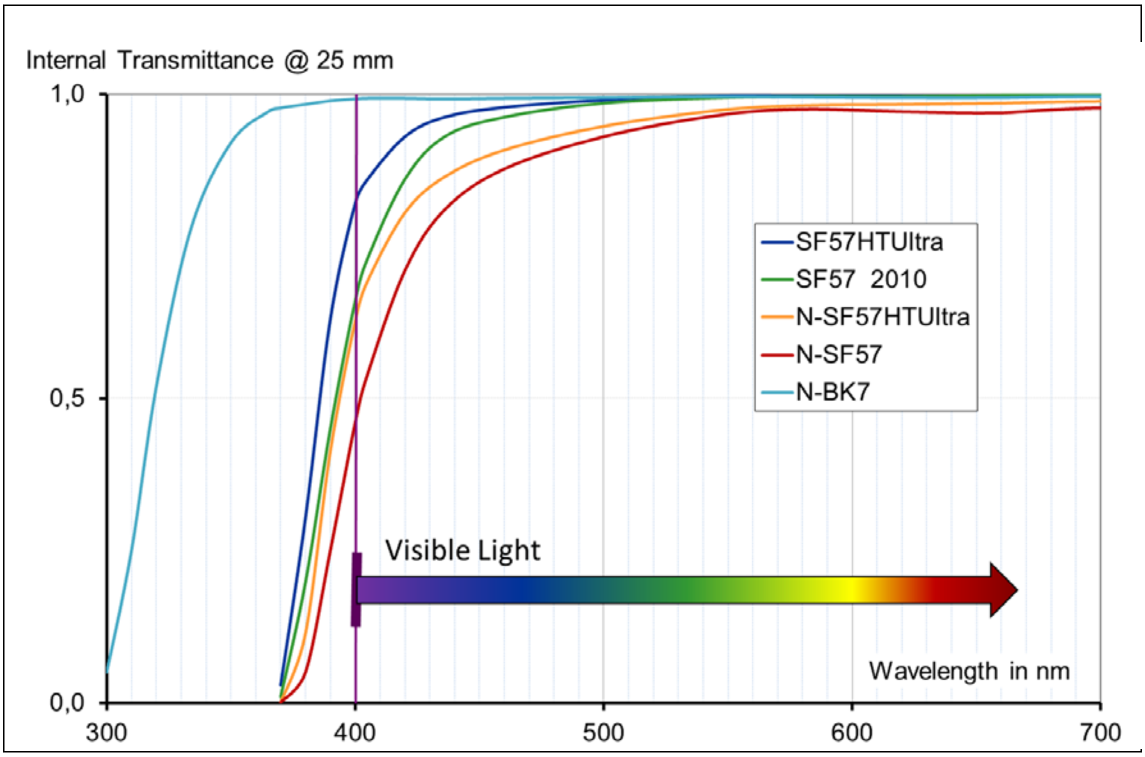


Figure 4. Graph of light transmission versus wavelength of light

SF57 and SF57HTUltra glass contain lead, whereas N-SF57 and N-SF57HTUltra are the lead free equivalents which have similar refractive index and Abbe number to the SF 57 versions, but with inferior blue light transmission. N-BK7(lead-free) is shown for comparison to show that even better blue light transmission can be achieved, but the other essential optical characteristics of N-BK7 make this unsuitable for many optical applications. The combinations of properties of these glasses are shown below (data from datasheets published by Schott).

Table 1. Comparison of properties of two lead-based and three lead-free optical glasses

Property	SF57	SF57HTUltra	N-SF57	N-SF57HTUltra	N-BK7
% Light transmission at 400nm	0.847	0.924	0.733	0.830	0.997
Refractive index (589.3nm)	1.8464	1.8464	1.8464	1.8464	1.5167
Abbe number	23.83	23.83	23.78	23.78	64.17

Table 1 shows that SF57HTUltra has the best overall combination of optical properties:- high proportion of shorter wavelengths visible light transmission, high refractive index and low Abbe number. Only glass containing lead has all of the essential characteristic needed for many optical applications.

The following example illustrates why a high percentage of light transmission through a lens is important:
Assume an optical system consisting of 10 lens elements (typical of professional camera and video lenses). The overall transmission $T = T(i)^{10}$

Transmission of individual lens element (Ti)	Overall Transmission (10 lens elements)
73,3%	4,5%
84,7%	19,0%
92,4%	45,4 %

The conclusion from this example is that optical glass with poor transmission characteristics (at any wavelength) leads to a tremendous waste of the light energy fed into the optical system.

A high light transmission percentage at shorter wavelengths is important for many applications. Some illustrative examples are:

Optical microscopes use a series of different lenses to obtain the required magnification and image clarity and it is important that the glass absorbs as little light as possible. Optical microscopes typically consist of objective, tube and scanning lenses as shown below.

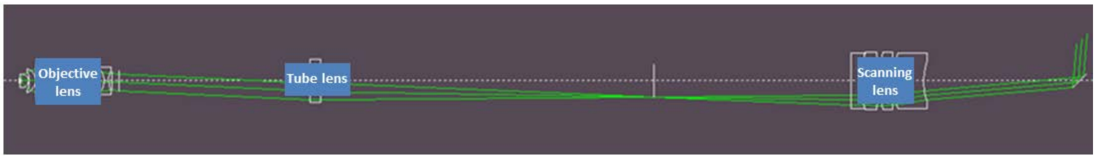


Figure 5. Light path in an optical microscope

Without lead-based glasses, very little blue – indigo light will reach the observers eye so that any blue / violet items are not visible and for many applications light of wavelengths in the UV/blue range (e.g. 355 or 405nm) are needed. UV wavelengths are also important for fluorescence microscopy. The same effect is also important with other high performance optical instruments where colour accuracy is important, such as professional still, video and television cameras, binoculars and telescopes. This is a serious issue with fluorescence microscopes which require a high transmission % in the UV / blue / violet range as well as high refractive index to allow the user to see small features in biological specimens.

High performance optical microscopes require many different lenses made from several different types of high quality optical glass. Glass types with a variety of optical properties are required which together provide the required performance. Among these properties are the refractive indices, dispersion and light transmission. A high percentage of light transmission in the blue spectral range and especially in the near ultra-violet part of the light spectrum and other essential characteristics are required for microscopes and this combination of properties can only be achieved with glasses that contain lead.

Because the refractive index of glass varies with wavelength, when a lens diffracts light, white light is split into its constituent colours and so it is necessary for other lenses to be added that recombine these colours to obtain excellent colour correction to prevent colour distortion of magnified images. It is possible to achieve the specific combinations of optical characteristics needed for microscopes only with lenses made with lead-containing as well as lead-free optical glass. High performance lens systems usually consist of many different lenses each of which is required to have a combination of specific properties and many combinations are achievable only with glass containing lead.

Glass families are defined by specific ranges of their combination of refractive index and dispersion (Abbe-number). Especially glass families as the Schott F, FS, KZFS, LF and LLF are vital for optical design in order to obtain maximum image quality, i.e. high contrast and optimal definition. This is because these glass families and the corresponding glass types are indispensable for colour correction (to compensate for longitudinal (X-axis) and lateral (Y-axis) chromatic aberrations) in the most demanding applications, such as with "high-end" professional microscopes.
Without leaded glass, optical design would need more lens elements to achieve some of the optical characteristics, but other characteristics will be impossible to achieve. Using more lens elements causes a higher level of stray light and reflections and the image quality will be significantly reduced.

Colour correction in microscopes

The most important and distinguished members in the portfolio of high-performance objective lenses used in microscopes are referred to as the families of Apochromates, W-Apochromates, C-Apochromates, α-Apochromates. These are the different types of optical microscope lens that all microscopes use and most microscopes have many more than four individual lenses. Apochromatic colour correction needs to be achieved over a broad spectral range and this optical property is defined by the international standard ISO 19012-2 "Designation of microscope objectives – Part 2: Chromatic correction".
Each microscope apochromate typically requires at least three lenses and the choice of at least one special glass with significant anomalous partial dispersion (lead-based) is needed for a clear undistorted image, e.g.

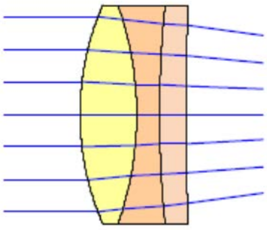


Figure 6. Schematics of an Apochromate

Optical Transmission

Internal transmission through a glass lens is another crucial optical property that depends strongly on the weight percentage of PbO, TiO2 or other materials. This is exemplified in the following figure (provided by Schott).

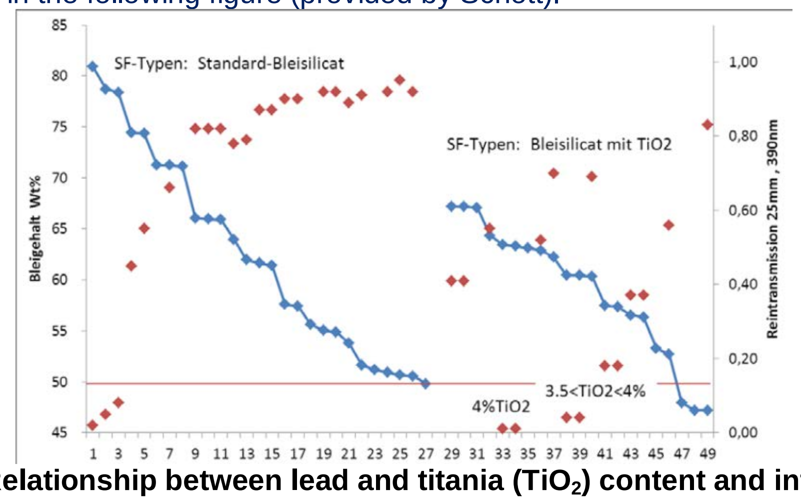


Figure 7. Relationship between lead and titania (TiO_2) content and internal transmission of light

This plot shows a nearly linear dependency between lead content and internal transmission. Substitution of lead by TiO_2 (as shown on the right hand side) reduces the internal transmission significantly, so is not a suitable alternative.
The difference between a lead-based glass and the lead-free substitute can be visualized most easily by plotting the internal transmittance vs. wavelength of light as in the following figure. This compares two nominally equal glasses SF6 and N-SF6 by Schott.

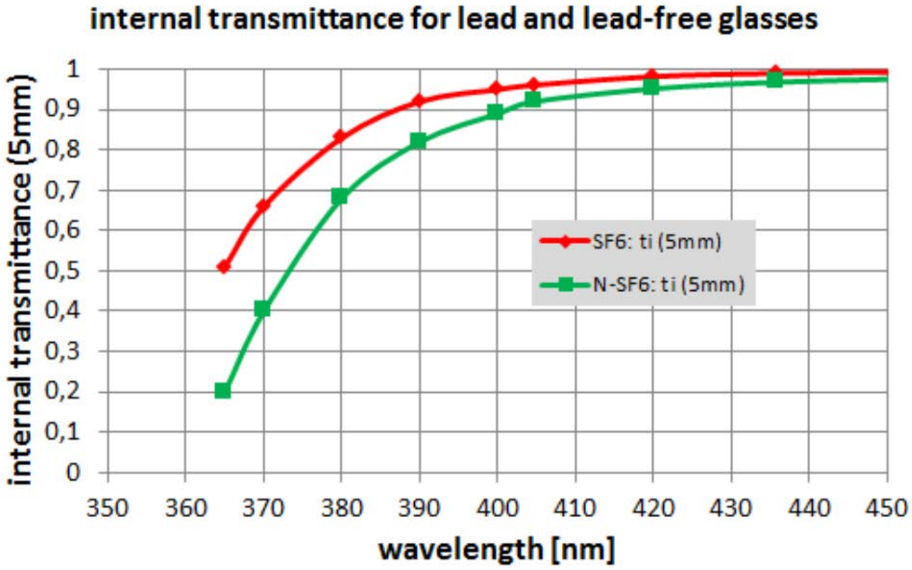


Figure 8. Spectral curves for SF6 (lead based) and N-SF6 (lead-free) flint glasses

SF6 glass is one of the few remaining SF glass types that is still available in the lead-based form and also in a lead free N-SF6 version. N-SF6 shows dramatically reduced internal transmittance at a standard wavelength of 365 nm through a 5mm glass thickness, whereas, typically the light in microscope objectives travels along much longer paths ranging from 25 mm to 100 mm.   In addition to this dramatically reduced transmittance between 365 nm and 410 nm, there is zero transmittance of lead-free glasses between 330 nm and 360 nm (see also figure 4).

Medical endoscopes have many lenses, including long rod-lenses of 200 to 500mm in length, which are used to examine internal organs which appear as mainly various shades of red. Light has to pass through the long length of glass before reaching the eye of the doctor or surgeon, so a high percentage of light transmission in all visible wavelengths by this glass is essential. These instruments also need good magnification to see small features. It is essential for a very high percentage of visible light wavelengths to be transmitted including the blue/violet range for doctors and surgeons to be able to clearly see and to differentiate between different types of tissue, such as healthy organs from cancerous tumours. Tumours often have very similar colour and appearance to surrounding healthy tissue and are visible only if the percentage of blue / violet light transmission is high. Medical endoscopes use a grade of glass F2HT (made by Schott) which has a light transmission percentage of >90% across the whole visible wavelength. The equivalent lead-free version transmits a relatively low percentage of light at lower wavelengths, as shown below (note that light is passed through 400mm thickness of glass unlike in figure 4 where light passes through 25 mm):

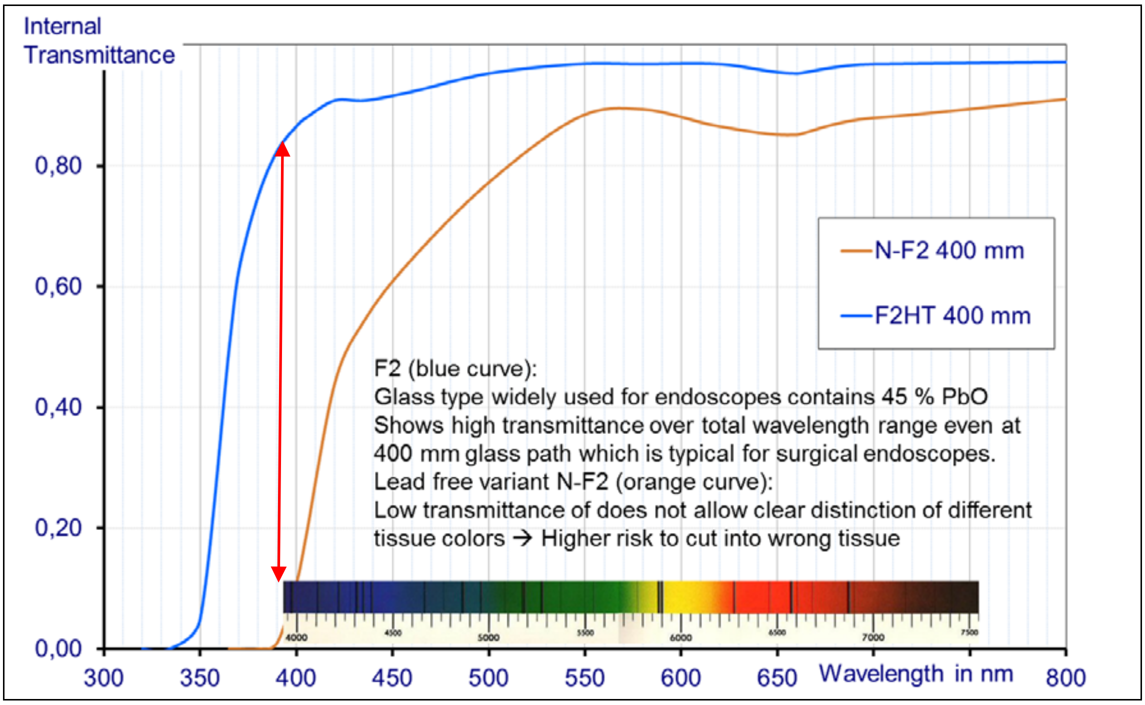


Figure 9. Comparison of light transmission performance of lead-based glass (400 mm thickness) used for medical endoscopes with nearest lead-free equivalent. Arrow at 390nm indicates lower wavelength limit for light detection by a typical human eye

F2 glass has a refractive index of 1.62 at 589 nm and an Abbe Index of 36.37, which cannot be achieved by high transmission grades of lead-free glass.
Medical endoscopes are usually side-viewed and so the image is seen via a glass prism which must have very high optical transmission in all wavelengths and not distort the image and only lead glass is capable of achieving the required performance.

LCOS (Liquid Crystal On Silicon) projectors give the best optical performance of all types of projectors[7]. Figure 10 below illustrates the light pathways that are used to create a colour image.

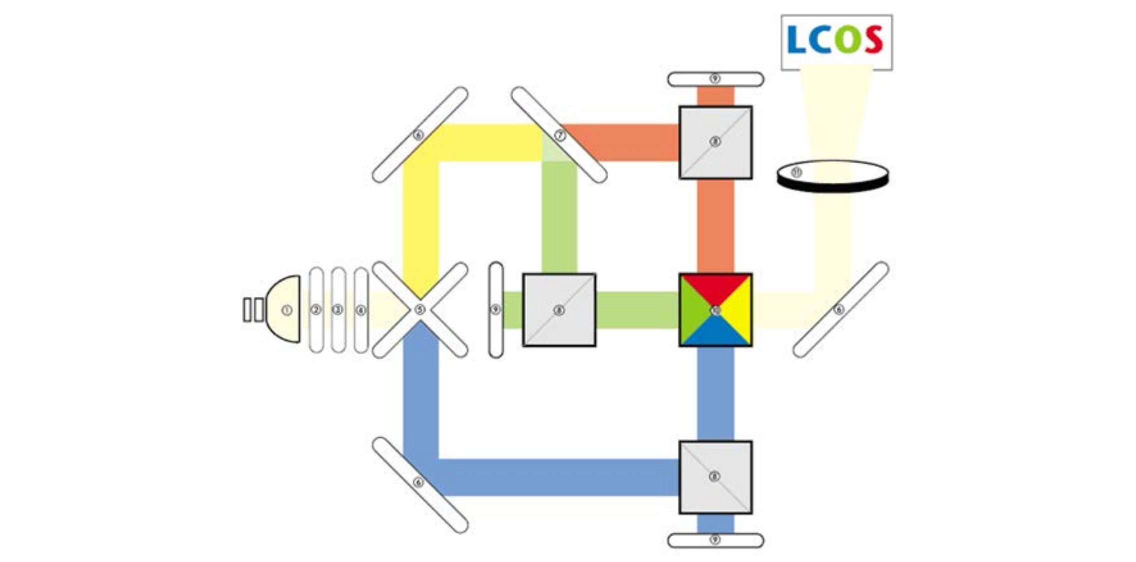


Figure 10. Light pathways in LCOS projectors

In LCOS projectors, white light from the lamp is split using three polarising glass beam splitters into the three primary colours, red, green and blue. Each coloured light beam passes through different optical pathways to create red, green and blue images which are then recombined to generate the image. It is essential that the light transmission of each colour is equal to achieve accurate colours, but the percentage of blue light transmission through most lead-free glasses is significantly lower than the other colours and so accurate colours can be produced only by attenuating the red and green signals. As a result more energy (ca. double) is needed to obtain an accurate colour bright image with lead-free glass than with lead-based glasses that have high blue light transmission efficiency. If more intense lamps are used, these generate more heat which potentially causes optical distortion due to heating of optical glass.

Fluorescence spectroscopy is an analytical technique that is used for analysis of some types of organic substances, molecular biology (e.g. cell and tissue analysis), medical research, cancer detection and other medical diagnostic procedures and industrial applications such as semiconductor analysis. All fluorescence techniques require optical glass with high percentage transmission at short wavelengths and fluorescence microscopes require many high quality lenses. Fluorescence spectroscopy operates by exposing the sample to light of a preselected wavelength which can be ultraviolet or visible light. Some materials absorb this light and then emit light of a longer wavelength by fluorescence in all directions. The emitted fluorescence is detected for quantitative analysis, imaging or mapping, depending on the type of instrument used. Medical diagnostics, for example often use near UV or blue/violet light to cause fluorescence and so a high percentage of light transmission at short wavelengths is essential.

Binoculars and telescopes

Classical Binoculars and Spotting Scopes have been improved over the past decades, not only in terms of image quality, but also transmission and brightness. The incorporation of electronics, such as laser range finding or imaging capabilities,

[7] http://www.projectorcentral.com/lcos.htm

into these products is a challenge. Additional functionality has to be incorporated without having a detrimental effect on the optical performance. To be able to observe those creatures that are active in the twilight hours, such as nightingales, earlier in the morning and bats, screech owls and other shy animals later in the evening, one needs the highest possible transmission. Obtaining clear images in twilight conditions is particularly difficult, as many lead free glass types start to absorb already in the blue spectrum. Light levels at dusk and dawn are very much less than during the day, but the human eye is able to compensate so that scenery does not appear to the naked eye to be a lot less bright at dusk than at midday, even though light levels are much less. When viewed through optical instruments such as binoculars and telescopes however, the optical performance is important to create a clear image from the very small amount of light received from small distant objects. Bright colour-accurate images are achieved only if as much light as possible of all visible wavelengths passes through the optical glass lenses of the instrument.

The graph below shows a spectral distribution of a typical spotting telescope and the spectral sensitivity curves of the human eye:

- (1) with the glass types being of lead-containing glasses (red spectral curve) and

- (2) the same device with the glass types being of lead-free glasses (blue spectral curve).

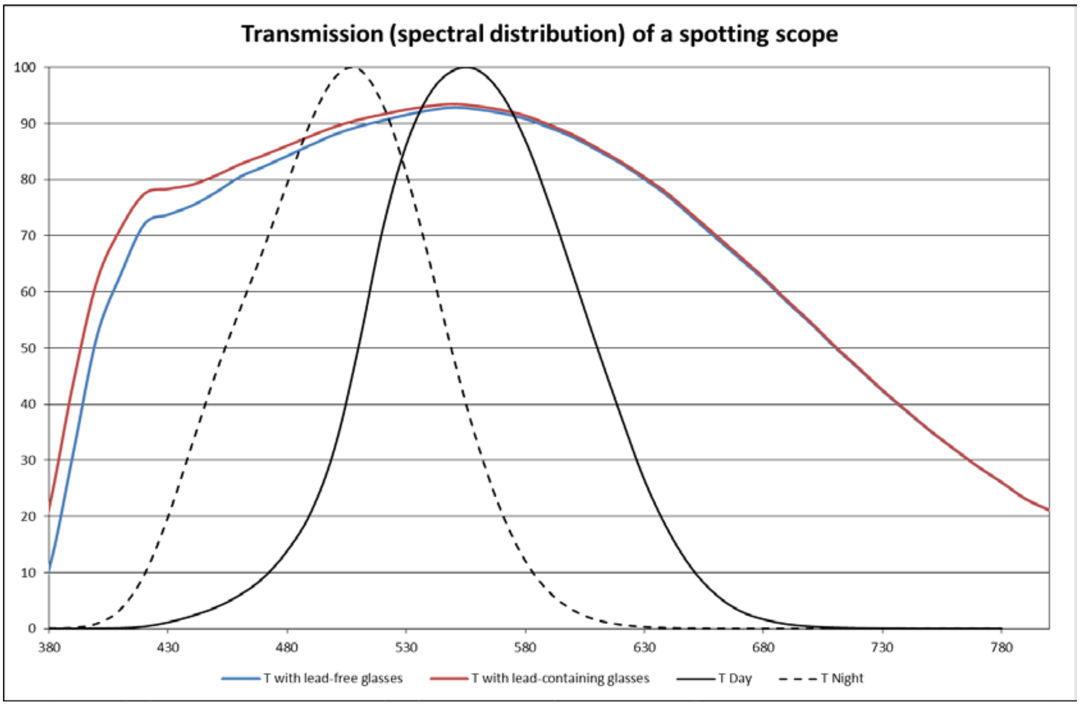


Figure 11. Light transmission with lead and lead-free glass compared with day and night human vision behaviour

In the example above the values τ_{Day} are 89% without lead and 90.0% with lead. A larger effect can be seen for the τ_{Night} value, where we calculate 86% without lead and 88% with lead. The difference between 86% and 88% may seem small but this is clearly noticeable to the human eye and can make the difference between seeing a creature or not.

The values τ_{Day} and τ_{Night} are calculated from these curves and give a sensitivity value for the human eye when using the device in daylight or at night. The value always is in the range from 0 to 1 (or 0% to 100%) and describes the perceived brightness of the image when watched through the device compared to the naked eye. The higher the value, the better the performance is for the user.

The calculation uses the eye sensitivity curves for day and nighttime watching as well as a standardized illumination source which corresponds to an overcast sky in the afternoon. Common values of τ_{Day} and τ_{Night} are around 85 to 95%.

A European manufacturer of these types of optical equipment values the transmittance of a device as very high on the list of important features for our users and has filed patent applications (US 2013-0258161 A1, EP 2605055 A1) which strive for protection of the use of lead-containing glasses in binoculars as well as the new lead-free glasses using extremely pure ingredients (Schott's so-called HT glasses. The patent applications are still pending (as of Jan 2014). The types of glass that could be used are as follows:

Glass	n_d	ν_d	τ_i**	Color code
N-BK7HT	1.51680	64.17	0.998	33/29
N-BAK4HT NEW	1.56883	55.98	0.993	36/33
N-SK2HT	1.60738	56.65	0.996	34/30
N-KZFS4HT NEW	1.61336	44.49	0.985	36/32
F2HT	1.62004	36.37	0.996	35/32
N-LASF45HT	1.80107	34.97	0.886	43/35
SF6HT	1.80518	25.43	0.941	41/36
N-SF6HTultra	1.80518	25.36	0.887	43/37*
N-SF6HT	1.80518	25.36	0.877	44/37
SF57HTultra	1.84666	23.83	0.924	39/36*
N-SF57HTultra	1.84666	23.78	0.830	40/37*
N-SF57HT	1.84666	23.78	0.793	41/37*
N-LASF9HT	1.85025	32.17	0.843	40/36*

* wavelength for transmittance 0.7 and 0.05
** 10 mm thickness, 400 nm wavelength

The table shows that there are Pb-free HT-glasses as well as Pb-containing HT-glasses. Example: For SF6HT the transmission at 400 nm is much better than for the Pb-free type N-SF6HT (94,1% instead of only 88,7%). The substitutes for SF6HT that are listed above have high τ_i values but have smaller refractive indices and different Abbe Indices and so cannot be used as alternatives.

Binoculars and spotting scopes more and more contain electronic functionality. Information is being superposed onto the image which always means an incorporation of a display along with a beam splitter in the optical viewing path. These displays (e.g. transparent LCDs) absorb a fairly high amount of light which counteracts all efforts to increase the transmittance of the device. This is an additional reason to use lead-containing glasses furthermore.

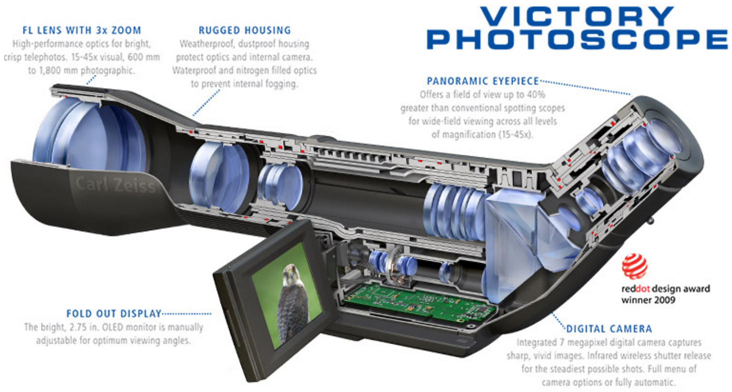


Figure 12. Novel design of telescope with inbuilt CCD camera (image courtesy of Carl Zeiss).

The image above shows a spotting scope with integrated CCD camera. Here it is of particular importance to realize a high percentage of light transmission, not only for the observation channel, but also for the camera path. Short exposure time for fast moving birds require a large amount of light in the camera path.

Low stress birefringence (low stress optical constant)

Low stress birefringence is essential for obtaining clear images without distortion and only lead-based glasses have both low stress optical constants and high refractive index. The graph below shows all types of optical glass produced by Schott. Only a very few types, all lead based, have high refractive index (close to 1.8) and very low stress optical constants (<1.0).

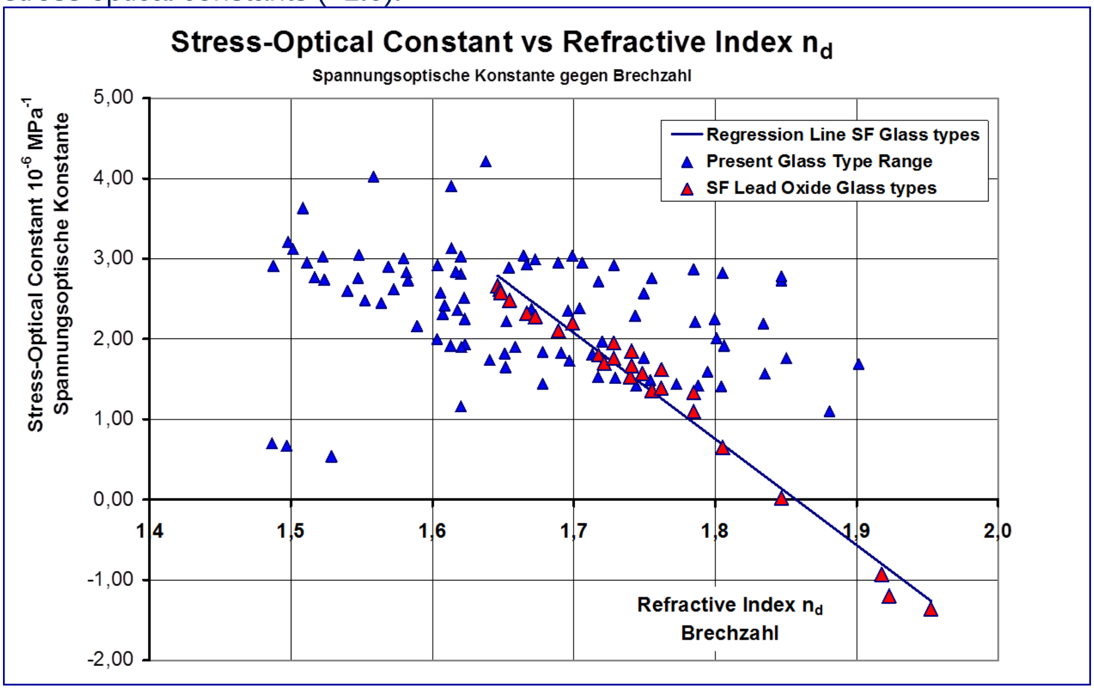


Figure 13. Graph of stress optical constant and refractive index for optical glasses.

Stress birefringence causes a variety of optical effects that make images appear blurred and colours to be changed. The image below compares the light output from a LCOS projector with lead-free and lead-based glass beam splitters.

Figure 14. Images from lead-free (left) and lead-based (right) glass beam splitters viewed in real LCOS projectors. Users expect the high quality display image, as above, to be absolutely black as in the right image

The lead-free N-BK7 glass beam splitter has a stress optical constant that is much larger (2.77×10^{-6} mm^2/N) than the SF57 leaded glass (0.02×10^{-6} mm^2/N) beam splitter so that the colours of white light are refracted unevenly resulting in the colour separation seen in the left image of figure 14. Stresses are induced by thermal effects, which in projectors are caused by heat from the lamp. Birefringence causes poor quality images in cameras and many other types of optical instruments which appears as poor contrast and distorted colours.

Colour aberration

The refractive index of all types of glass varies with wavelength so that blue light is refracted more than red and this causes colour aberrations in images seen as coloured fringes. Lead-free glasses are typically inferior showing greater aberration than lead-based glass and this is because the difference between the refractive index of blue and red light is larger with lead-free glass than with lead-based glass. Examples are shown below.

Figure 15. Colour photograph showing coloured fringes (arrowed)

Contrast and image clarity can also be affected as is shown by the pair of images below.

Figure 16. Photographs obtained with lead-based glass lens (left image) and lead-free glass lens (right image). Note colour fringes on right image which is also blurred.

Chromatic aberration is removed by using combinations of lenses with different properties. Axial chromatic aberration is prevented by combining one concave (negative) and one convex (positive) lens either as:

A. the positive lens element is assigned a significantly higher Abbe number than the negative lens, while the negative lens element has to be allocated a higher refractive index.
B. the positive lens element is assigned both a higher Abbe number and higher refractive index than the negative lens element.

In both cases, the difference between the Abbe numbers should be as great as possible but to obtain a compact design (necessary for microscopes and photographic and video camera lenses) with smallest chromatic aberration, the second option "B" is preferred and the positive lens should have as high as possible refractive index. In these designs, the negative lens must have a low Abbe number this is provided by the SF range of leaded glass and their lead-free equivalents. However, only the leaded versions transmit a high percentage of blue light and so lead-free glass is not suitable.

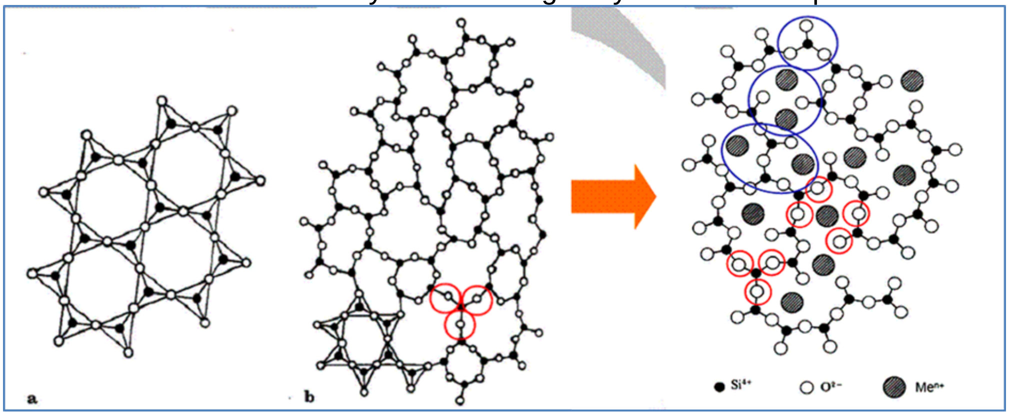
4. Content of substance in homogeneous material (% weight): Most optical glasses contains 40 – 70% by weight of lead oxide, so contain from 37 to 65% of lead, although manufacturer reports that glass containing 20% (for light guides) and 80% (for optical glass lenses)of lead are also used.

5. Amount of substance entering the EU market annually through application for which the exemption is requested:

Please supply information and calculations to support stated figure.
We estimate that global production of lead based optical glass used in EEE is 1250 tonnes per year. About 40% of EEE is placed on the EU market so this will contain 500 tonnes of lead based optical glass. The average lead content is ca. 55% lead so 275 tonnes of lead.

6. Name of material/component: "Glass" of varied compositions which typically contain Si, Na, Ca and other elements as various mixed oxide compositions.

Glasses are characterized by their non-regularly ordered amorphous atomic structure



crystalline SiO_2 amorphous SiO_2 mulit-component glass

Figure 17. Atomic structures of silica and multi-component glass

Glass is produced from different constitutional components:

1. Glass formers form glass network

- SiO_2 silicon oxide
- B_2O_3 boron oxide
- P_2O_5 phosphorus oxide

2. Network modifier break up the network

alkaline oxides:

- $L_{i2}O$ Lithium oxide
- Na_2O sodium oxide
- K_2O potassium oxide

Alkaline earth oxides such as CaO

Rare earths elements

Etc.

3. Intermediate elements added as oxides may also be bound into the network

- Al_2O_3 aluminum oxide
- MgO magnesium oxide

4. Additional agents introducing special properties

- Coloring ions
  Fe, Mn, Cr, V, Co, Cu, Cd, Se, .
- Laser active ions
  Nd^{3+}, Yb^{3+}, Er^{3+}, …
- Ionizing radiation stabilization compounds
  CeO_2
- etc.

A crystalline structure with composition well defined by chemical formula
e.g. silicon dioxide: quartz, is:

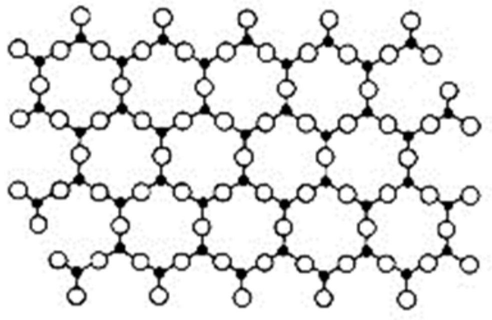


Figure 18. Atomic structure of crystalline silica

An amorphous structure still having a well-defined composition and precise chemical formula, e.g.: amorphous silicon dioxide: fused silica

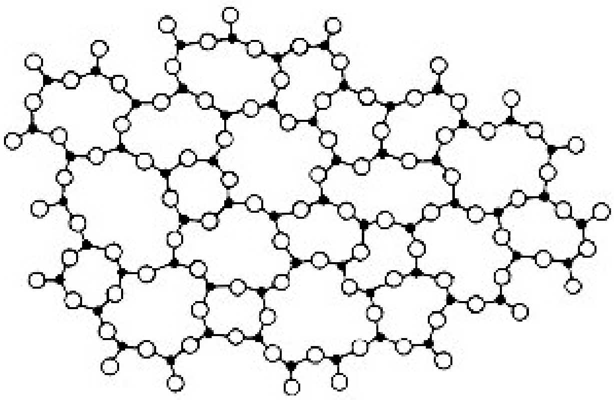


Figure 19. Atomic structure of amorphous silica

An amorphous structure produced on the basis of a defined recipe, but without composition that can be well defined by a chemical formula, e.g. sodium - lime glass with a broad range of possible contents of sodium and potassium. In the figure below, only sodium ions are shown for simplicity.

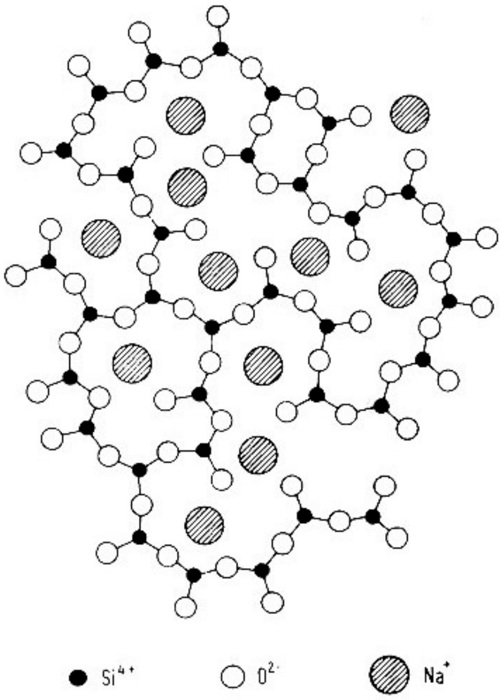


Figure 20. Atomic structure of a soda-lime glass (showing only Si, O and Na)

7. Environmental Assessment: This exemption is required because no substitute materials or designs are available that provide the required performance. Therefore a full LCA is not required, however the impact of lead in all life cycle phases is explained here.
LCA: No – LCA is not applicable to this exemption renewal request

Mining and extraction of lead: The US Geological Survey publishes global primary lead production and this was 5.2 million tonnes in 2012, a quantity that has been increasing since 1990. In addition, there are significant amounts from secondary sources so in 2012, 10.5 million tonnes of lead was used (International Lead Association). Most lead is used in batteries and in rolled and extruded products; lead in electrical equipment is a relatively minor use and in optical glass it is an extremely minor use (0.01% of global consumption[8]). Therefore restrictions on the use of lead in optical glass will have no impact on this life cycle phase.

Manufacture of lead-based optical glass: Optical glass is usually manufactured by combining the appropriate mixture of ingredients and heating these in a furnace to cause the ingredients to react to form the melt. This material is cast and cooled at a controlled rate to form the optical glass. This creates large pieces of glass that are cut and shaped by grinding to form the required optical components.
Production of molten glass potentially emits metal oxides including lead oxide. However, glass melting is in scope of the Industrial Emission's Directive (IED) 2010/75/EC and strict limits are imposed on hazardous emissions, so that no risk occurs. The IED imposes strict emission limits on lead and other harmful substances from a wide variety of industrial processes, including glass melting using Best

[8] -Primary plus secondary was 10.5 million tonnes in 2012 (ILA)

Available Technology Reference (BREF) guides that Member States use to impose permit requirements for industrial installations. The glass BREF was revised and a new version published in 2012 (as 2012/134/EC) and includes limits of emissions of all hazardous substances that are based on the best technology available in the EU. Therefore, as long as IED is effectively enforced, glass melting processes should not pose a risk to human health or the environment.

Cutting and grinding glass creates glass powder and small pieces that are disposed to landfill. Lead in the form of glass pieces should not leach out to cause pollution in well managed landfill sites (see end of life). Grindings have a high surface area and are classified as hazardous waste because of the lead content, although this lead is not readily soluble. Any leachate from hazardous waste sites is collected and treated before transfer to water sources, although this type of waste is covered so that rain water cannot percolate through the waste.

Use phase: In use, optical glass is very stable and inert. 100% of the lead content remains within the glass under all normal use conditions of electrical equipment.

End of life: At end of life, optical glass from WEEE may be either landfilled with the WEEE (i.e. no recycling) or be passed through the WEEE recycling process with other electrical equipment. Glass is relatively heavy so after dismantling, shredding, physical separation by density, etc. the glass is likely to occur in the metals fraction. Scrap metals have a value and so are usually recycled thermally.

- Landfill – . The behaviour of lead in landfill is very complex as it (and other metals) can react with other constituents to form various compounds. A report by the European Environment Agency[9] states that measurements of leachate from EU landfill sites have found that lead is… "not generally present at significant concentrations in leachates from municipal landfills. Mean and median values for all metals were well below concentrations routinely determined in household sewage that is typically flushed from a domestic property". This result may be because lead becomes immobilised by clays and other materials in landfills to form insoluble metal complexes. Lead compounds are not volatile so air emissions will not occur. Only 500 tonnes of lead optical glass is placed on the EU market annually whereas 100 million tonnes of municipal waste is disposed of to landfill[10]. If all lead optical glass is disposed to landfill, the concentration is only 5ppm and as this glass is large pieces will be relatively inert.
- Thermal treatment – scrap metals may simply be heated to melt them or heated with reducing agents such as carbon to convert oxides to metals. Simply heating will melt the glass which will mix with other non-metallic and non-volatile materials to form a "slag" that is inert and sent to landfill. Lead will not leach out of this material as explained above. Under reducing conditions such as in a smelter used to recover copper from printed circuit boards, some lead compounds may be reduced to lead metal which is volatile at the process temperature, the vapour then oxidises and has to be collected. This material is a hazardous waste. Lead will be present in the feed-stocks used for smelting processes such as those used for WEEE recycling from many materials other than optical glass. In WEEE it will occur in a variety of RoHS exempt forms (e.g. high melting points solders), but smelters also treat ores

[9] "Dangerous substances in waste" Jürgen Schmid et al, February 2000, European Environment Agency (please add interlink source there, see footnote in exemption renewal application for 13b)
[10] 500kg of waste per capita in 2009 of which 200kg per capita is landfilled from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Municipal_waste_statistics EU population is 500 million.

and refinery by-products as a mixture with WEEE to achieve maximum yields and efficiencies and these materials will also contain lead[11]. Therefore lead is collected and depending on the design of process, is either recovered for reuse or is waste for disposal. Recovery and disposal of lead from waste will occur whether there is lead present in optical glass or not.

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?
Optical glass – see answer to Q4.A3
.

(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?
See answer to Q4.A3

5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste
1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

WEEE from used EEE devices is collected and treated according to the WEEE directive. Business WEEE usually has a high metal content and so is sold for recycling in the EU by the last user and should comply with EU laws on waste recycling. Consumer WEEE is usually collected as mixed types of WEEE at municipal waste sites or even as separated WEEE from other municipal waste, depending on the maturity of the collection and treatment techniques available in the EU Member States for WEEE. Electrical equipment sold primarily to consumers contains very little optical glass that contains lead as these materials are used primarily in B2B products, although there are some exceptions listed in the answer to Q4.

Closed loop systems do not exist due the very large variety of applications for optical glass. Optical glass is used as small components of electrical equipment which follows a variety of routes at end of life. Some is refurbished and then sold to second users, some will be recycled although glass parts are usually not removed before metal recovery processes. A small remaining proportion might be landfilled

2) Please indicate where relevant:

- Article is collected and sent without dismantling for recycling
- Article is collected and completely refurbished for reuse
- Article is collected and dismantled:
    - The following parts are refurbished for use as spare parts:
    - The following parts are subsequently recycled:
- Article cannot be recycled and is therefore:
    - Sent for energy return
    - Landfilled

Electrical equipment containing optical glass is not collected or recycled separately from other types of electrical equipment and so is recycled using the same procedures as other WEEE. Some types of equipment (such as cameras) is re-sold

[11] Hoboken site visit 2012, download from http://www.umicore.com/investorrelations/en/newsPublications/presentations/

to second (or third, etc.) users both within the EU and outside of the EU but no data is available on quantities.

3) Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:

- In articles which are refurbished
- In articles which are recycled
- In articles which are sent for energy return
- In articles which are landfilled

EU industry complies with all applicable waste legislation. Refurbishes where this is practical, recycles materials where possible and uses landfill only as a last resort. No data available on the quantities of optical glass that is refurbished, recycled or landfilled. Energy recovery from glass is not applicable.

6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

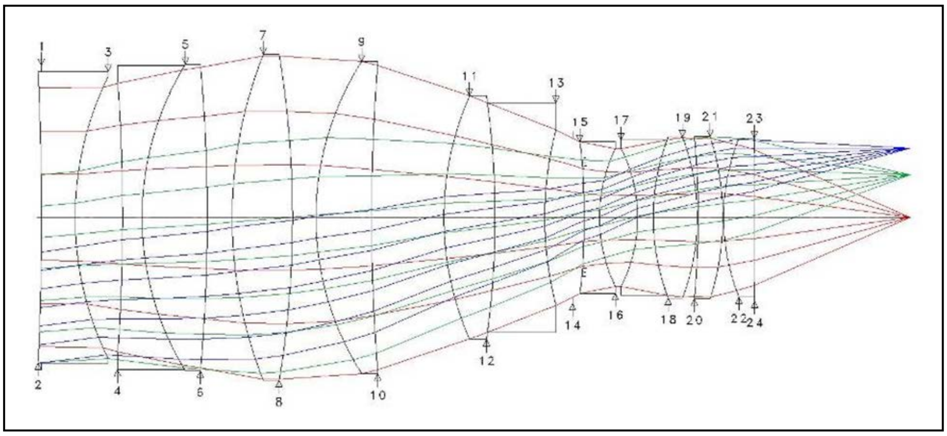
Three options are considered here as potential alternative substances or designs.

- Lead-free optical glass
- Plastic lenses
- Alternative equipment designs

Alternative lead-free glass is compared with lead-based glass in the answer to Q4.A3. Some additional information on the differences in characteristics of lead-based optical glass and alternative glass types is as follows:

Professional camera lenses for photography and for cinematography have superior performance to camera lenses used on cameras sold to consumers. This is because, images frequently need to be magnified by large amounts and any errors become very obvious at high magnifications. Therefore the best quality is essential. To achieve the best performance, professional cameras consist of many different lens shapes which are made from different types of glass. Two example lenses are shown to illustrate the need for lead-based glass;

i. A typical professional lens is shown below. The version that uses lead-based glass requires 12 individual lenses whereas to achieve similar image quality, 14 lead-free glass lenses are needed.



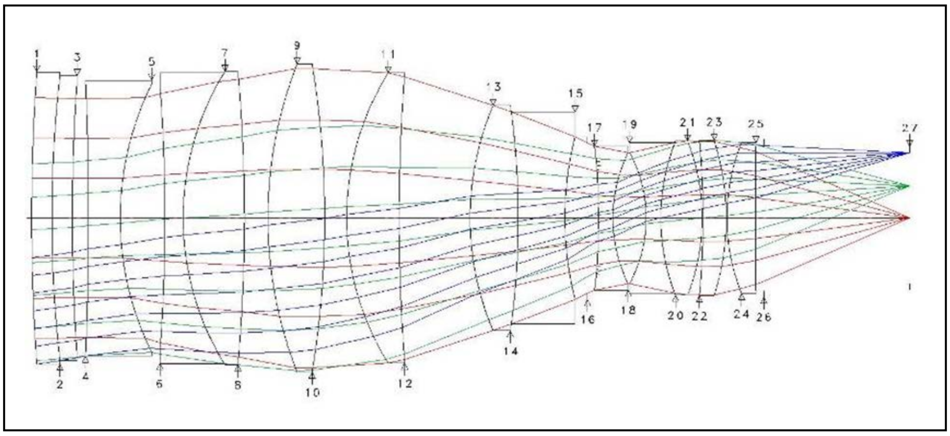


Figure 21. Comparison of lens designs, showing that lead-free designs need more glass material – upper diagram Lead-based glass lenses with 12 components, lower diagram Lead-free glass lens with 14 components

The effect of increasing the number of lenses from 12 to 14 has a significant negative effect. There will be more transmitted light absorbed through 14 lenses than through 12, especially at shorter wavelengths. Also, at every lens surface, some light is reflected which degrades image quality and two additional lenses means four more surfaces for reflections to occur. It is not possible to quantitatively measure this difference and inferior quality lead-free lenses are not made but the difference in image quality between these two lenses will be obvious to a professional photographer.

ii. "Fish-eye" lenses are used with cameras for photography, cinematography and television cameras. These use relatively thick lenses such as the example shown below.

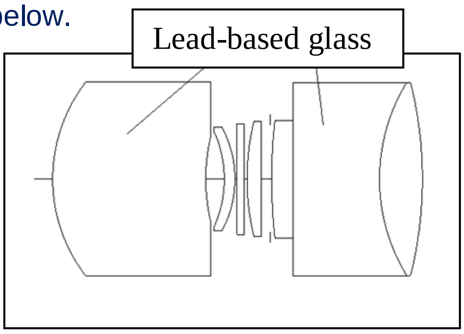


Figure 22. Design of a "Fish-eye"-lens structure for a professional camera

The two very thick lenses must have low light absorption to obtain clear bright images with good colour accuracy. The table below shows the difference in light transmission losses for the same lens made with lead-free glass and with lead-based glass:

Wavelength (nm)	656	622	587	566	546	516	486	460	435	420	404
With lead	0.985	0.985	0.985	0.985	0.984	0.977	0.963	0.941	0.901	0.828	0.657
Lead-free	0.947	0.954	0.961	0.960	0.956	0.928	0.892	0.854	0.782	0.699	0.464
Difference	0.038	0.031	0.024	0.024	0.028	0.050	0.071	0.087	0.119	0.129	0.193
Difference in % transmission loss	3.83	3.15	2.47	2.47	2.85	5.08	7.34	9.21	13.23	15.53	29.35

At blue wavelengths, such as 420nm, only 70% of blue light is transmitted with the lead-free version whereas 83% of blue light is transmitted by the lead-based glass lens. As a result the lead-free fish-eye lens will give a redder coloured image.

Plastic lenses have very different optical and physical properties to lead-based glass. One of their limitations for many applications is their inferior heat stability when compared to glass; for example, the temperature inside projectors can reach well over 100˚C and many polymers will distort or melt at these use temperatures. High refractive index (R.I.) spectacle lenses are stable <120˚C and the plastic lens material with the highest refractive index is MR174 (made by Mitsui) with R.I. of 1.74 which has a heat distortion temperature of 78˚C[12].
Polymers also have much higher coefficients of thermal expansion (CTE) than glass so that temperature changes can cause dimensional changes which alter the optical characteristics. Typical linear CTE values are:

- Glass SF57HT Ultra 9.2×10^{-6}/K
- Polycarbonate 70×10^{-6}/K

Most clear transparent polymers such as polycarbonate and acrylics have relatively low refractive indices (<1.6) making them unsuitable for high performance magnification applications.
The table below summarises the main differences between lenses made of glass with plastic lenses.

Property	Glasses	Plastics
Refractive index	1.44 to 2.1 achievable (highest for lead is 2.1)	1.49 to 1.74
Tolerance (i.e. variation in characteristics of commercial lenses)	Low (±0.0001) can be achieved, so variation is very small	Estimated at ±0.001
Abbe number	Broader range (20 to >80) especially to low dispersion values	23 – 58 is possible
Transmittance (through 3mm)	>99% achievable	85 – 91% typically
Birefringence	2 to 10 nm/cm	2 to >40 nm/cm
Density	Lead-based are ca. 5 g/cm^3. This offers advantages and disadvantages	1 – 1.2
Water absorption	Zero (so moisture has no effect on performance)	All plastics absorb water causing changes to properties (as they swell) and also potentially degradation can occur. From 0.01% to 0.3%
Thermal expansion	SF57HT Ultra is 9.2 x 10-	Range is 47 to 80 x 10^{-6}/K.

[12] http://www.mitsuichem.com/special/mr/resources/img/MR_Brochure_en.pdf

	^{6}/K, all glasses 4.5 to 13 x 10^{-6}/K.	This causes optical changes with temperature and thermal degradation
Refractive index thermal dependence	Smaller range of - 0.7 to + 1.2 10^{-5}/˚C	-8 to -14 10^{-5}/˚C
Resistance to damage	Relatively hard so not easily damaged.	Soft so easily scratched
Exposure to UV light	No effect	Discolours and degraded
Heat resistance	Resistant to temperatures created by lamps and laser light sources	Lamps and lasers can easily cause deformation or even make holes
Medical sterilisation	Completely resistant	May be damaged at sterilisation temperature. Viruses and bacteria can survive within scratches which plastics are more prone to than glass
Thermal conductivity	Lead-glass is relatively high so equilibrates faster than lead-free glass and plastics	Slow to equilibrate so can distort due to uneven heating

The figure below shows the Abbe numbers and refractive indices of optical plastics that are available and all types of optical glass.

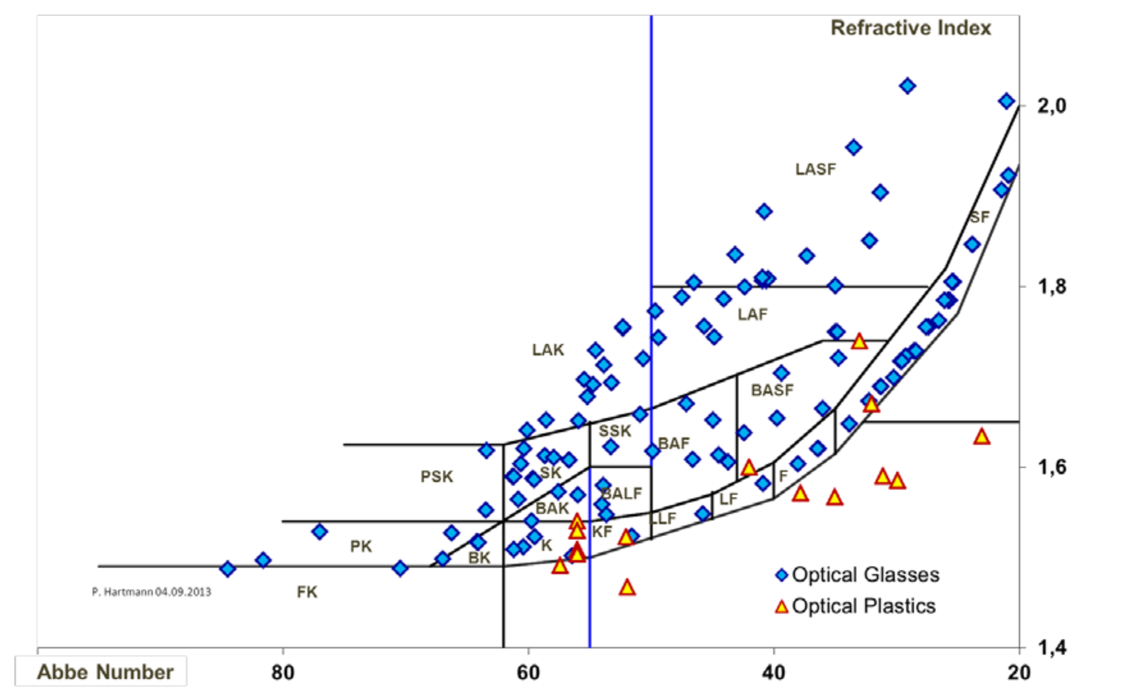


Figure 23. Comparison of characteristics of optical plastics and optical glasses

Alternative equipment design

Different designs of equipment, but without leaded glass that provide the same function and performance where leaded optical glass would be, if available, viewed as an alternative. However, leaded glass is used in a very wide variety of applications as described here and no alternative designs have been or are likely to be developed with equivalent performance for a very large variety of applications. One example described above is of LCOS projectors. Alternative designs of projector are widely used but it is acknowledged that LCOS designs give the best optical performance.

(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application
Reliability is not an issue as lead-free alternatives are not able to provide all of the essential characteristics needed for the many diverse applications of lead-based optical glasses.

7. Proposed actions to develop possible substitutes
(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.
There are a limited number of elements in the periodic table available that can be combined to form optical glasses. Also, those combinations that exist form glasses only within relatively small composition ranges. After many decades of research, all possible combinations of elements have been prepared and evaluated and this has shown that for many applications, there are no alternatives to compositions that contain lead. As a result the only feasible alternative for each application is to search for alternative designs, but this is usually not possible.

For all applications, research has already been carried out and when lead-free substitutes were found, they are used. Further research into alternative designs is uncertain and may never be successful due to the demanding combinations of essential characteristics. Therefore it is not possible to predict how long this type of R&D will take or whether substitutes can be found for all of the diverse applications. It is very possible that it will never be possible to replace leaded glass in all applications.

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.
See answer to Q7A

8. Justification according to Article 5(1)(a):
(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)?

- Authorisation **No**
- SVHC **No**
- Candidate list **No**
- Proposal inclusion Annex XIV **No**
- Annex XIV **No**
- Restriction **No**
- Annex XVII **No**
- Registry of intentions **No**
- Registration **Registration is not applicable to articles.**
  Registration of glass is exempt (Annex V of REACH).

Optical glass containing lead is manufactured from lead compounds and other compounds, some of which are classified as SVHCs, but these substances chemically react during the glass producing process to form complex mixed oxide materials that are not classified as SVHCs and are not listed in any of the REACH Regulation Annexes.

2) Provide REACH-relevant information received through the supply chain.
Not applicable

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?

- Yes. Consequences?
- **No**. Justification: - See below

Performance and characteristics would be significantly inferior if lead-free glass were to be used. The following examples illustrate why substitution is not possible:

Example 1: Endoscopy: Without lead-based glasses, some surgical procedures will not be possible as tumours and other features will not be visible. Endoscopes for engineering applications such as the examination of turbine blades inside aero engines will be much more difficult or impossible so that small cracks may not be seen at an early stage. This will pose a safety risk to aircraft users.

Example 2: High-end camera lenses rely on several types of lead-based glass. Without these, image quality will be inferior.

Example 3: Surgical microscope: Surgeons use these to see very small features inside people's bodies. Image quality without lead-based glass will be inferior which will result in a loss of precision. It is necessary to cut out small tumours without healthy tissue or leaving tumour fragments. Some procedures may be impossible as obtaining the same level of magnification, may require larger lenses with the objective needing to be closer (due to lower refractive index of equivalent lead-free glass) to the parts being viewed so that there may be insufficient space to operate.

2. Can the substance named under 4.(A)1 be substituted?

Yes.

- Design changes:
- Other materials:
- Other substance:

No.

Justification: For the reasons explained in answer to previous question and elsewhere in this submission.

3. Give details on the reliability of substitutes (technical data + information):
Not applicable, glass composition does not affect reliability of EEE, only the performance and ability to provide the required functions.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to

1) Environmental impacts:
2) Health impacts:
3) Consumer safety impacts:

☐Do impacts of substitution outweigh benefits thereof?**,**
Not applicable as these are not reasons for needing this exemption. However, not allowing this exemption would negatively affect all three, for example:

1) Environmental impacts: Lead glass lenses are used in chemical analysis equipment that is used to monitor environmental pollutants. This would be less accurate without lead in optical glass so that pollution is more likely to remain undetected.

2) Health impacts: Several types of medical device require lead in optical glass in order to provide the optimum diagnostic and treatment performance. This is explained in the answer to Q4.3A and 8B1. Human health would be negatively affected if lead in optical glass could not be used.

3) Consumer safety impacts: None known to applicant

Optical glass containing lead is also used for spare parts to repair and refurbish equipment. The availability of these types of glass depends on a healthy market for new products as optical glass production cannot be scaled-down.
Manufacture of lead-based optical glass on a small scale is impractical as it is too difficult to precisely control the glass composition and the optical properties of the glass. If lead-based optical glass were permitted to be used only to make spare parts, this glass would have to be made in much larger batch sizes than the amount of glass needed for spares only to ensure that the optical properties are correct. This would consume energy and raw materials to make glass that may never be used and so additional waste would be created. If no more lead-glass were made as a result of ending exemption 13a, it will not be possible to repair used equipment that requires these types of glass as replacement spare parts and so these would become waste.

Please provide third-party verified assessment on this:

(C) Availability of substitutes: None are available for the uses of optical glass where lead based glasses are currently used.

a) Describe supply sources for substitutes: None

b) Have you encountered problems with the availability? Describe: Not applicable

c) Do you consider the price of the substitute to be a problem for the availability? No

d) What conditions need to be fulfilled to ensure the availability? Unknown

(D) Socio-economic impact of substitution: Not applicable for this exemption renewal request

☐What kind of economic effects do you consider related to substitution?

Increase in direct production costs -

Increase in fixed costs -

Increase in overhead

Possible social impacts within the EU

Possible social impacts external to the EU

Other:

If all current optical designs would have to be redesigned (i.e. without this exemption, although alternatives do not currently exist and cannot be envisaged from current technology), a huge effort in R&D would be required by the optical industry to attempt to solve optical problems again that have already been solved (by use of leaded glass) with utmost professional skill to develop useful and long lasting products for users of optical glass.

The new EU framework program for R&D (HORIZON 2020) is intended to encourage innovative new technologies with funding provided by the EU and from industry. Without this exemption, a lot of money would have to be withdrawn from R&D funds that were intended for innovative new products to instead look for substitutes. There is also no guarantee that alternatives could be found so the money spent will give no benefit to the EU. However, Spectaris considers it is clearly better to look for new optical solutions (instead of alternative materials, which has already been extensively researched), since optical techniques and products are a key enabler for many other industries. This option would support the long-term EU aim to stay ahead of other competing economies, which currently are not imposed to the same prohibitions as the EU industry without this exemption. Loss of competitiveness would harm EU industry and cause job losses, but it is not possible to quantify this impact.

9. Other relevant information
Please provide additional relevant information to further establish the necessity of your request:
See attached document “Additional technical information for exemption 13a renewal request”.

10. Information that should be regarded as proprietary
Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:
None.