A. Lead in optical glasses

1) Example of microscopes (including surgical microscopes)

① Application of anomalous dispersion by lead content in optical glass

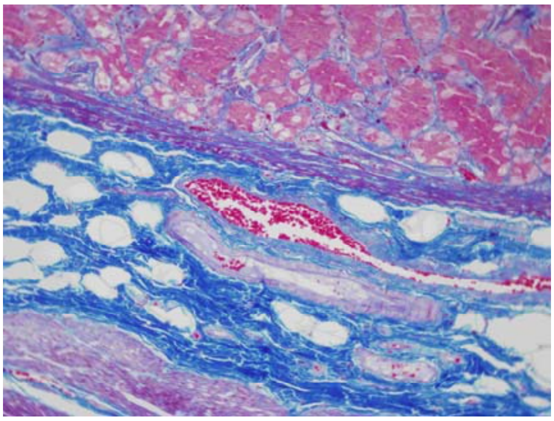
Anomalous dispersion of glass is essential for the purpose of eliminating secondary spectrum chromatic aberration (Apochromat correction). This chromatic aberration correction level is a critical factor that affects the image quality of optical glass used for microscopes, in particular. Even if lead-free glass material with an equivalent refractive index and Abbe's number is developed, it is impossible to achieve the desired Apochromat performance especially for highest-grade objective lenses with a high aperture number when the anomalous dispersion degrades. Fig. 1 (E) shows an example of stain used for pathology researches and tests. As shown in the photo, the sample is stained in different colors using several pigments, and pathology tests are diagnosed by identifying the extremely fine structure based on these colors. It can be construed that the extremely fine structure cannot be identified using just an objective lens made of lead-free lens and this would slow down pathology researches and lower the test efficiency. Fig. 1 also shows enlarged images of the pinholes (extremely small hole) of an Apochromat objective lens (A) and non-Apochromat objective lens (B). The Apochromat objective lens forms a shape image with very little purple halo around the pinhole. In genetic researches, chromosomes are studied in many colors. If the Apochromat performance degrades, the proper focus cannot be achieved for each color, which will seriously compromise the reliability of the test results. (See Fig. 2.)

(A)

(B)

(C)

(D)



(E)

Fig. 1 (A): Apochrmat objective lens image (B): Non-Apochromat objective lens image (C): Objective lenses (D): Typical microscope (E): Example of stain used for pathology researches and tests

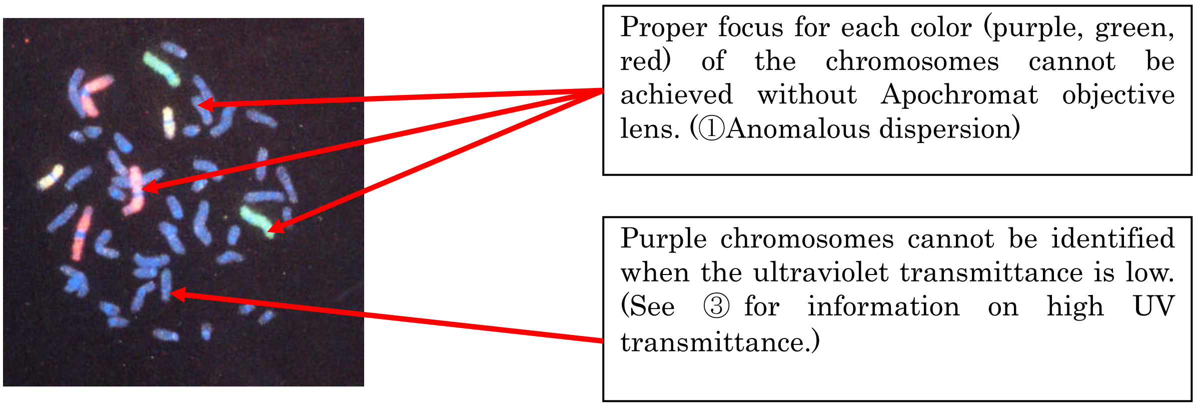


Fig. 2 Fluorescence observation image of chromosomes used for genetic researches

② Example of the differences in anomalous dispersion

To illustrate the difference in anomalous dispersion of lead-containing glass material and lead-free glass with the same refractive index and Abbe's number, the differences between the glass materials BPH5 and S-NBH5 manufactured by OHARA INC. are described below. The refractive index and Abbe's number of the lead-free glass material S-NBH5 are the same as that of the lead-containing glass material BPH5. The anomalous dispersion ($\Delta\theta$ g,F, $\Delta\theta$ i,g) of S-NBH5, which is important for correcting the chromatic aberration in the short wavelength region, is half or less than that of BPH5. Therefore, it will be impossible to design an Apochromat objective lens unless lead-containing glass material such as BPH5 is used.

	BPH5 (OHARA) Lead-containing glass material	S-NBH5 (OHARA) Lead-free glass material
Refractive index nd	1.65412	1.65412
Abbe's number ν d	39.7	39.7
Anomalous dispersion $\Delta\theta$ g,F Anomalous dispersion of F line (486.13nm) and g line (435.83nm)	-0.0069	-0.0036
Anomalous dispersion $\Delta\theta$ i,g Anomalous dispersion of g line (435.83nm) and i line (365.01nm)	-0.0311	-0.0132

Table 1. Differences in the anomalous dispersion of BPH5 and S-NBH5

In another example, the difference between the lead-containing glass material LAM7 and lead-free glass material S-LAM7 manufactured by OHARA INC. is described below. Although the refractive index and Abbe's number of both glass materials are the same, the sign of anomalous dispersion ($\Delta\theta$ C,t), which is important for correcting the chromatic aberration in the near-infrared region, is different. Therefore, S-LAM7 cannot be used as a substitute for LAM7 to manufacture objective lenses that can correct chromatic aberration in wide wavelength ranges up to the near-infrared region. It is impossible to design a near-infrared objective lens unless lead-containing glass material is used.

	LAM7 (OHARA) Lead-containing glass material	S-LAM7 (OHARA) Lead-free glass material
Refractive index nd	1.74950	1.74950
Abbe's number ν d	35.3	35.3
Anomalous dispersion $\Delta\theta$ C,t Anomalous dispersion of C line (656.27nm) and t line (1013.98nm)	-0.0101	0.0018

Table 2. Difference in anomalous dispersion of LAM7 and S-LAM7

③ High UV transmittance of lead-containing optical glasses

Fluorescence observation is considered to be highly important in modern life science researches. In particular, fluorescence observation by excitation of ultraviolet rays (330 to 385nm) is widely used for measuring calcium concentration in cells and stain of nucleus. If the ultraviolet transmittance deteriorates, these observations will become impossible, and it can be predicted that the progress of life sciences will be significantly affected as a result. Fig. 2 shows the fluorescence observation image of chromosomes. If the ultraviolet ray transmittance (330 to 385nm) of optical glass deteriorates, the light that excites fluorescent pigments will not reach the sample and consequently it will be no longer be possible to identify the purple chromosome.

Therefore, a high-transmittance glass material in the range from 330 to 385nm is required for ultraviolet rays fluorescence observation. When lead-containing glass is compared with lead-free glass with the same refractive index and Abbe's number, the former achieves high UV transmittance and this characteristic is crucial for fluorescence observation. For example, the refractive index (nd) of the lead-containing glass material PBM8 is 1.59551 and its Abbe's number (ν d) is 39.3, whereas the refractive index (nd) of the lead-free glass material S-TIM8 is 1.59551 and its Abbe's number (ν d) is 39.2. The refractive indexes and Abbe's numbers of both glass materials are very close. Their transmittance characteristics in the ultraviolet rays region (330 to 385nm), however, are very different. Fig. 3 shows the internal transmittance (transmittance excluding the reflection loss of optical glass) of 10mm-thick glass materials PBM8 and S-TIM8. The 340nm internal transmittance of the lead-containing glass material PBM8 is 0.82, while the 340nm internal transmittance of the lead-free glass material S-TIM8 is zero. If lead-containing glass material cannot be used, the fluorescence observation images that use ultraviolet rays will be considerably dark and will seriously affect tests and researches that use the fluorescence observation technique.

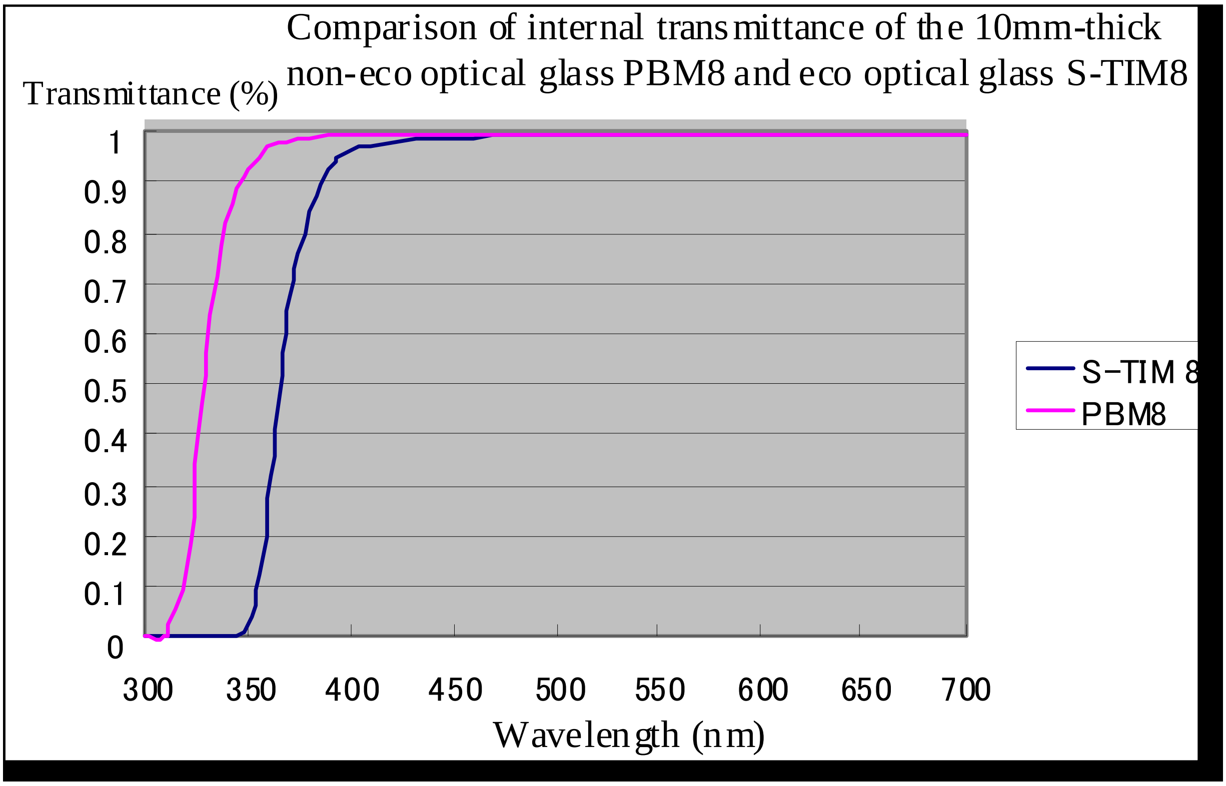


Fig. 3 Comparison of the internal transmittance of lead-containing optical glass PBM8 (OHARA) and lead-free optical glass S-TIM8 (OHARA)

2) Application in endoscopes

① Fiber glass containing lead with high transmittance (light guide)

The light from an external light source is guided to an observation target location using optical fiber glass (light guide) for endoscopes (Fig. 4).

Compared with applications of a general optical glass (such as a lens), the optical path length of the light guide of endoscopes and surgical microscopes is very long. Therefore, even a slight change (degradation) of transmittance will have a large effect on the ultimate optical performance. The role of the light guide is to transmit light as much as possible to the tip of the endoscopes in a wide angle. To achieve this purpose, the refractive index of core glass material must be as high as possible and transmittance must be optimal. Lead is the substance required to achieve both a high refractive index and transmittance. Fig. 5 shows graphs of the drop in the light amount based on the difference in light guide lengths and the drop in the amount of light based on the difference in the viewing angles.

Of late, in addition to simple white illumination observation, fluorescence observation and special observation using light of a specific wavelength are performed for early stage detection and treatment of affected areas in a patient's body. Therefore, high transmittance is demanded for an optical fiber that is used to guide lights for various purposes. Although plastic fiber and fiber glass made of lead-free glass are available today, only optical fiber glass containing lead can satisfy the functional requirements of endoscopes in a wide wavelength ranging from the ultraviolet region to infrared region.

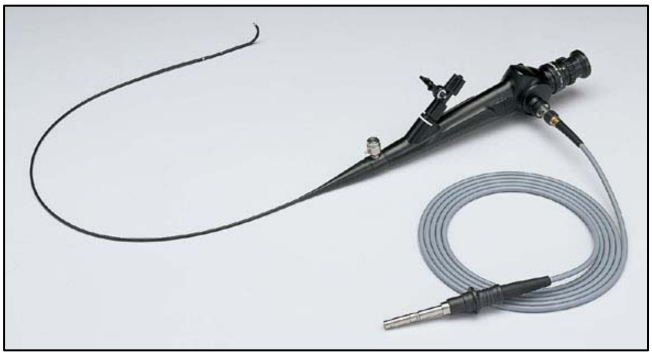


Fig. 4　Medical-use endoscopes

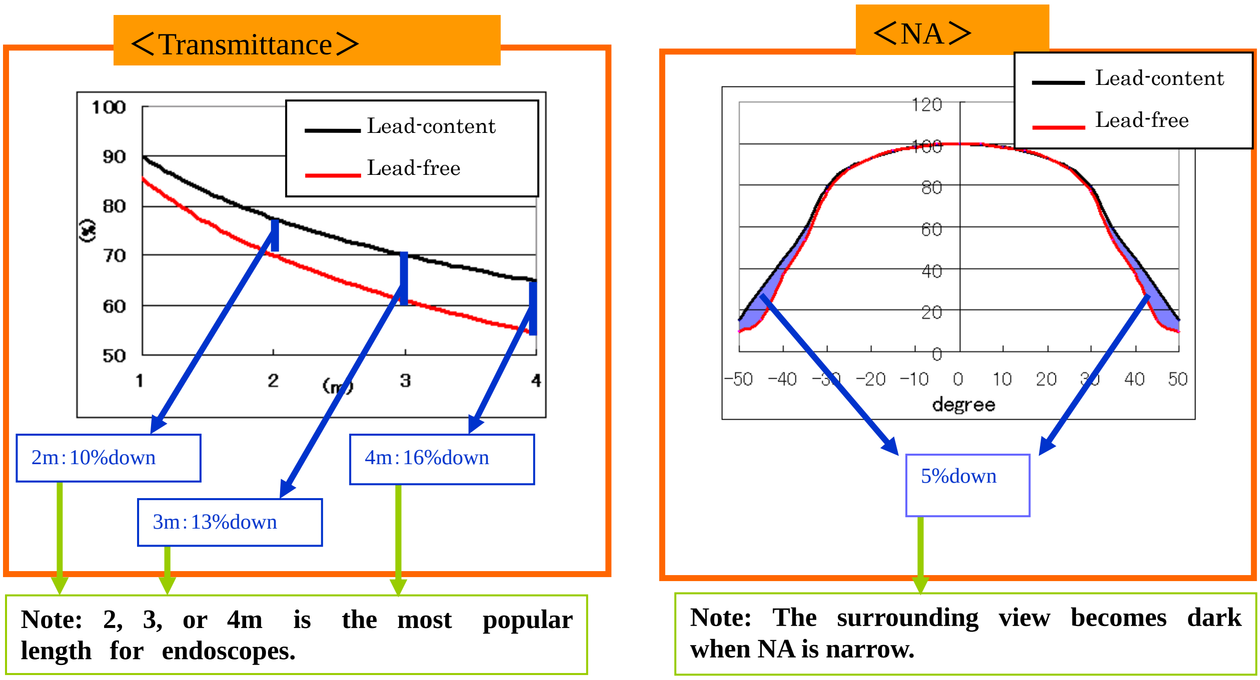


Fig. 5　Light amount based on the difference in light guide lengths and light amount based on the difference in viewing angles

② Lead-containing glass mold aspherical lens

There is always a demand for further size reduction of endoscopes because they are relatively non-invasive diagnosis treatment instruments. Therefore, it is necessary to use aspherical lens in order to reduce the lens outside diameter and the number of lenses for endoscopes. Furthermore, chemical and mechanical resistance against various cleaning, sterilizing, and disinfecting processes, and biological adaptability are demanded for the materials used for the exterior of endoscopes.

Existing endoscopes use lead-containing optical glass for aspherical light lens. The temperature characteristics and fluidity characteristics suitable for molding have to be attained by networking PbO to produce the aspherical shape of the lens. Molding glass containing titanium and niobium has been developed as a substitute for lead-containing aspherical glass. These molding glasses, however, normally use a large amount of materials with inferior chemical characteristics such as alkaline metal, in order to maintain the molding characteristic. Chemical and mechanical resistance of these glasses to various cleaning, sterilizing, and disinfecting processes are inferior compared with lead-containing glass. Therefore, these glasses are not suitable as material for the exterior of endoscopes.

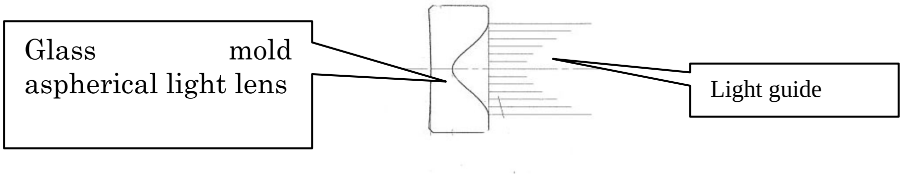


Fig. 6　Tip of the lens of endoscopes

B. Application to industrial-use optical instruments

Optical glasses and filter glasses perform an important function for microscopes and optical application equipment products in the industrial sector of Category 9 products. Endoscopes are used for aircraft engine checks and sewer checks, and also as an important emergency tool for saving lives during disasters such as earthquakes. The several tens of meters of optical fiber glass assembled in such equipment require even higher transmittance than medical-use endoscopes.

Fig. 7 Typical industrial-use microscope, industrial-use stereomicroscope, and industrial-use endoscopes

C. Technological possibilities

1) Substitute for optical glasses

We are pushing ahead with research and development of substitute technologies for optical materials (used in applications mentioned above). According to our interviews with in-house engineers and glass manufacturers, there has been no presentation of researches on either substitute materials or actual examples of patent applications. Particularly, the technological difficulties of research and development related to substitute materials for optical filter glass is extremely high, and therefore, there is no prospect of development of substitutes for optical filter glass at present.