Environmentally-Resistant ZnS Lens for Far-Infrared Cameras

1. Outline

Far-Infrared (wavelength: 8 - 12μm) Cameras can visualize targets by sensing their surface temperature without using any light source. For this reason, this type of camera is used widely in night surveillance systems, night vision systems installed in vehicle, household electrical appliances, and other equipment and apparatus. Although the market for these cameras expanding steadily at an annual rate of about 10 percent or more, they are very expensive. Cutting the prices of both infrared sensors and Far-Infrared optical lenses is essential to keep popularizing the cameras into the future. Development of lower-priced lenses is urgently required.

To meet the above requirement, we mass-produce zinc sulfide (ZnS) lenses for Far-Infrared Cameras by introducing a mold-forming/sintering process as an alternative lens of expensive germanium lenses. The ZnS lenses have an excellent optical performance and are less expensive than germanium lenses.

We have recently developed a new, highly durable ZnS lens that can be reliably used in in-vehicle cameras, outdoor surveillance cameras, and other optical apparatus that are operated in severe conditions and are expected to become more popular in future. The new lens is coated with highly durable diamond-like carbon (DLC) and provided with an athermal system that does not require focusing even when the temperature fluctuates significantly. In addition, we focus to release standard lenses (**Photo 1**) that can be supplied at a reduced price even in small lots.

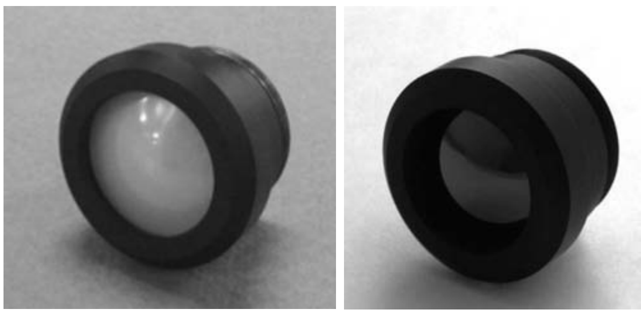
2. Features

2-1 DLC coating on ZnS lenses

Far-Infrared optical windows and lenses used in outdoor surveillance cameras, in-vehicle cameras, and other outdoor optical apparatus are usually coated with DLC to protect them from harsh conditions. We coated our ZnS lenses with DLC whose superior environment resistance has been proven.

Far-Infrared transmission for DLC-coated ZnS lenses (thickness: 3 mm) are shown in **Fig. 1**. Average transmission of the ZnS lenses in a wavelength range of 8 to 12μm, which is an important property required of Far-Infrared Cameras lenses, was 84.4%. This value is acceptable in practical use. The spectral characteristics (dashed curve) of conventional anti-reflection (AR)- coated lenses are also shown for reference in this figure.

Environmental test results for DLC-coated ZnS lenses are shown in **Table 1**. The test results did not show any change in the appearance or transmission before and after each test, or film peeling after the tape adhesion test.



AR-coated lens DLC-coated lens

Photo 1. Appearance of lenses

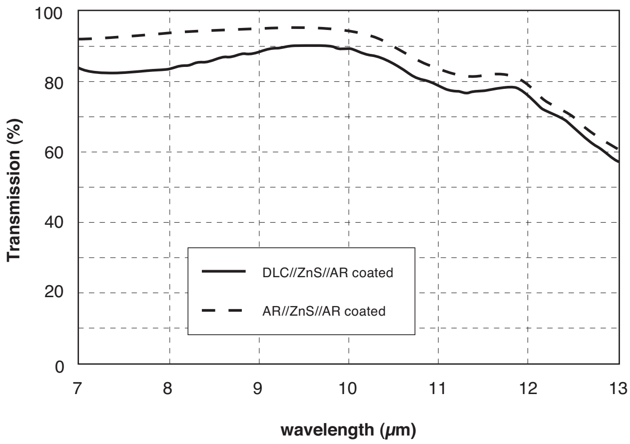


Fig. 1. Far-Infrared transmission

2-2 Athermal system

Requirement for the temperature resistance of lenses is becoming severer as their outdoor use expands. When a lens is exposed to a different temperature, the refractive index of the lens material changes and the lens barrel expands or contracts. Since these physical phenomena displace the lens focus and deteriorate the modulation transfer function (MTF※1), an index of lens resolution, the focus must be readjusted. The refractive index of a ZnS material has a low temperature dependence (dn/dt) as shown in **Table 2**; therefore this material is relatively less sensitive to temperature change. However if the temperature fluctuates substantially, deterioration of MTF cannot be ignored.

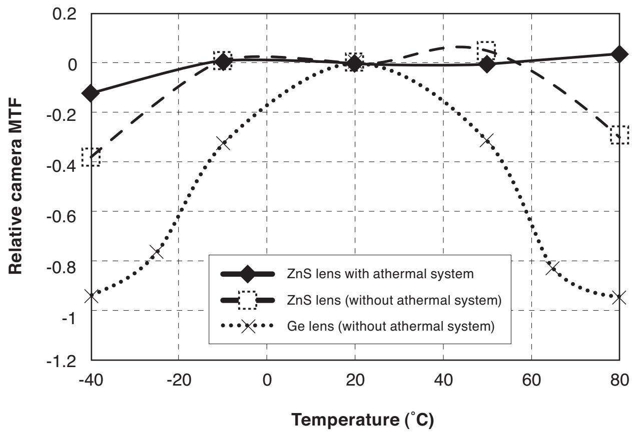
We made the most of ZnS's low dn/dt to successfully develop and mass-produce an athermal (temperature compensation) system that is simple and compact in construction and performs stably in a wide temperature range. **Figure 2** shows the camera MTF measurement results for low-high temperature in a range from -40°C to +80°C. A conventional germanium lens, which is not provided with an athermal system, has a large dn/dt and degrades the MTF in both the high and low temperature ranges. In contrast, the ZnS lens did not significantly degrade the MTF in the temperature range of -20°C to +70°C, even though it was not provided with an athermal system, demonstrating that this lens could be put to practical use. However, in temperature ranges other than the above, the MTF of this lens deteriorates by 30 to 40% with respect to the value at room temperature. The ZnS lens provided with a newly-developed athermal system exhibited a stable performance with its MTF being maintained within 10% of the value

Table 1. Environmental test results for DLC-coated ZnS lenses

Test item	Test condition	Test result	Remarks
Humidity	80°C / 95%RH, 770 h	Passed	MIL-F-48616
Thermal shock	5 cycles of -60°C×1h ↔ 180°C×1h	Passed	–
Adhesion	Tape test	Passed	MIL-F-48616
Abrasion	Severe 20 stroke	Passed	MIL-F-48616
Salt spray	Saltwater concentration: 5%, 200h	Passed	JIS- Z- 2371
Acid rain	SO_2 amount: 0.2L, 14 cycles	Passed	DIN-50018 0.2S
Weathering	UV + water, 192h	Passed	JIS-D-0205 WAN1S

Table 2. Comparison of the characteristics of Far-Infrared optical materials

Item	Zinc sulfide (ZnS)	Germanium
Refractive index at 10 µm	2.200	4.003
Abbe's number (8 - 12 µm)※2	22.7	942
dn/dt [K^{-1}]	4.1×10^{-5}	40.0×10^{-5}



$$\text{Relative camera MTF} = \left[\frac{\text{Camera MTF (each test temperature, each specimen)}}{\text{Camera MTF (room temperature, each specimen)}}\right] - 1$$

Fig. 2. Low-high temperature camera MTF measurement results

Table 3. Environment test results for ZnS lens with athermal system

Test item	Test condition	Test result	Remarks
Low-high temperature MTF	-40 – +80°C, along axis, 20 lp/mm	Passed	–
High-temperature storage test	100°C × 650h	Passed	MIL-F-48616
Humidity test	80°C/95%RH × 400h	Passed	MIL-F-48616

Table 4. Lineup of standard lenses

Model No	Focal length (mm)	F- No※3	Image circle※4 (mm)	Coating	Average transmission from 8 to 12 μm	Horizontal angle of view (°)※5 (Sensor type)	Athermal system
#349	19	0.96	10	AR	77%	24(A) / 12(C)	Not provided
#349DLC	19	0.96	10	DLC	72%	24(A) / 12(C)	Not provided
#550	18.8	0.985	10	AR	79%	24(A) / 16.4(B)	Provided
#550DLC	18.8	0.985	10	DLC	74%	24(A) / 16.4(B)	Provided
#516	12.8	1.00	10	AR	77%	34.7(A) / 24(B)	Optional
#516DLC	12.8	1.00	10	DLC	72%	34.7(A) / 24(B)	Optional

Table 5. Corresponding sensors

Type	Pitch	Number of pixels
A	25 μm	320 × 240 (QVGA)
B	17 μm	320 × 240 (QVGA)
C	25 μm	160 × 120 (QQVGA)

at room temperature. Environmental test results for the new lenses are shown in **Table 3**. As this table shows, the test lenses maintained their performance stably even under environmental loads. The test results confirmed that the newly-developed lenses provided with an athermal system have high operational reliability.

3. Lineup of Standard Lenses

As described above, market needs for inexpensive Far-Infrared optical lens are increasing as the Far-Infrared Cameras market expands. We succeeded in reducing ZnS lens production costs by introducing a molding process. However, the considerable initial cost of preparing molding dies and other tools has forced us to limit this production system to mass-produced lenses. To meet the market need for smaller numbers of inexpensive lenses, we are required to standardize these lenses. On the other hand, infrared image sensor makers are striving to cut sensor production costs.

Under these circumstances, we have developed standard lenses that are suitable for use with general-purpose sensors and can meet the current market needs. The lineup of standard lenses we have developed recently is listed in **Table 4**, and the sensors corresponding to these lenses are listed in **Table 5**. Some types of the newly-standardized lenses are coated with DLC and/or provided with an athermal system so that they can meet any one of the use conditions.

The focal length of the newly-standardized lenses is 19.0 mm, 18.8 mm or 12.8 mm. We will expand the lineup by adding wider-angle lenses.

Technical Term

※1 MTF : An index that represents the resolution of a lens.
A large MTF gives a sharp image.

※2 Abbe's number : The inverse of the dispersive power that represents the wavelength dispersion.
A large Abbe's number represents an optical material with low chromatic aberration (A phenomenon in which different wavelengths of light are not all focused at the same time.)
A large chromatic aberration coefficient represents a blurred image.

※3 F-No. : An index that represents the intensity of light that can pass through a lens.
A small F-No. means a lens of a large aperture that can produce a bright image.

※4 Image circle : The imaging area of a lens

※5 Horizontal angle of view : The horizontal angle of the view of an imaging area