ニコンZマウント用大口径レンズ NIKKOR Z 58mm f/0.95 S Noctの開発

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Development of the NIKKOR Z 58mm f/0.95 S Noct Large aperture lens for the Nikon Z mount

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2019年10月，「NIKKOR Z 58mm f/0.95 S Noct」を発売した．大口径・ショートフランジバックのニコンＺマウントだからこそ実現できた開放Ｆ値0.95．「Noct」を冠したこの大口径レンズの設計思想は，1977年に発売された「AI Noct Nikkor 58mm f/1.2」に端を発している．ここでは，新生Noctに詰め込まれた新しい技術とニコンのDNAについて説明する．

The NIKKOR Z 58mm f/0.95 S Noct was launched in October 2019. It has a maximum aperture of f/0.95 which facilitates usage of the Z-mount, which has a large diameter and a short flange back. The design concept of the fastest lens, to which the term “Noct” was added, started with the AI Noct Nikkor 58mm f/1.2 launched in 1977. In this study, we explain a new technology and DNA of NIKON packaged into the new and updated “Noct.”

Key words　ニコンＺマウント，交換レンズ，大口径レンズ，ノクト，開放Ｆ値0.95
Nikon Z mount, Interchangeable lens, large aperture lens, Noct, maximum aperture 0.95

1 Introduction

The Nikon Z mount system lens “NIKKOR Z 58mm f/0.95 S Noct” was launched in October 2019 (Fig. 1).

Fig. 1　NIKKOR Z 58mm f/0.95 S Noct.

2 History of Development

The Nikon Z mount system has a maximum inner mount diameter of ϕ55 mm and a short flange back of 16 mm. With these features, this product demonstrates the potential of the Z mount by realizing both the highest peak performance of NIKKOR to date, and the brightness that surpasses the maximum aperture of f/1. In addition, this product is expected to open up new possibilities for visual expression.

3 Features of NIKKOR Z 58mm f/0.95 S Noct

The most remarkable features of the lens include the maximum f/0.95 ultra-large aperture, the fastest in NIKKOR history[*1], and a superior optical performance that alters the common knowledge of conventional large-aperture lenses. Aberrations, ghosting, and flares are suppressed through special glass materials for the optical system consisting of 17 lens elements in 10 groups, and by adopting the latest optical technologies such as ground Aspherical surface and ARNEO coat (Fig. 2).

Another major feature of the lens is that it is a manual focus lens. At f/0.95, which has an extremely shallow depth of field, the requirements for focus accuracy are extremely stringent. By matching the high-definition electronic viewfinder (EVF) of the Nikon Z mount camera with the manual

[*1] In interchangeable lens for Nikon camera

focus mechanism of this product, it is possible to exactly adjust the focus according to the intention of the photographer.

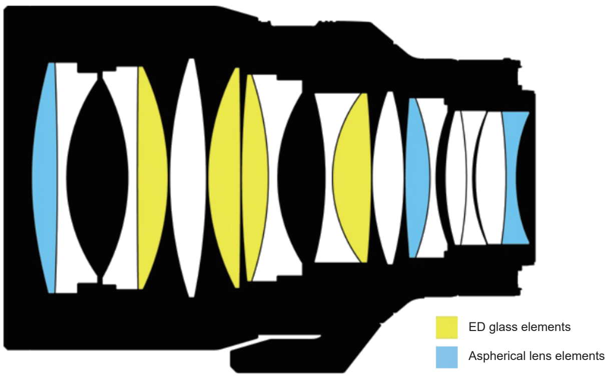

Fig. 2 Lens configuration diagram.

Moreover, it has a high-quality exterior design suitable for a lens that symbolizes the Nikon Z mount system. The details of these outstanding features are explained hereafter.

4 The World of Maximum Aperture f/0.95

"Spherical aberration is proportional to the cube of the aperture". This is the basis of the optical design derived from the third-order aberration theory[1]. In short, if the spherical aberration for f/2.8 is taken as 1, it will be approximately 2.8 times for f/2, 8 times for f/1.4, and approximately 25.6 times for f/0.95. Both f/2.8 and f/1.4 are said to have large apertures; hence, with this comparison alone, f/0.95 can be said to be far superior. Since the value of F is determined by "focal length ÷ effective aperture", F has a close physical relationship with the lens size and light exposure amount. According to the specifications, the effective aperture of f/0.95 is about $\sqrt{2}$ times that of f/1.4, and its exposure is about twice as bright. Further, as brighter F value corresponds to larger effective aperture size, the product size tends to increase. However, even if the focal length and the F value are the same, the product size may differ, as there are some uncertain aspects due to other factors, such as performance, mechanism, design, operability and so on.

A large aperture means the lens has a shallow depth of field and a large blur. There are four major factors that affect the blur size: the focal length of the lens, the F value, the shooting distance, and the distance between the subject and the blur target. Among these, the F value is the only one that does not affect the composition and can be easily set. Moreover, to create beautiful circular blurs in the illumination, vignetting of the lens is important. Even at maximum aperture, it is ideal to have no vignetting as it also has the adverse effect of increasing the lens size. In that respect, vignetting can be improved by stopping down. For example, if f/0.95 is narrowed down by 2 stops, it will still be less than f/2, and be able to achieve large circular blurs without vignetting. This also has the advantage of improving the resolution.

The need for a larger aperture is often questioned due to the improved high-sensitivity characteristics of the sensor and the focusing accuracy associated with the shallow depth of field. However, since lower sensitivity has a wider dynamic range and less noise than a higher one, the benefits of being able to shoot with low sensitivity are greater. Since the depth of field is approximately proportional to the F value, focusing with f/0.95 is extremely severe. However, the resulting picture is one that can only be enjoyed with the large aperture of f/0.95.

Finally, the F value is also related to the resolution limit. If the aperture is narrowed down, the resolution could deteriorate due to the influence of diffraction. The F value is related to the numerical aperture (NA) during image formation by the following equation:

$$NA = \frac{1}{2F} \tag{1}$$

As the F value becomes smaller, NA increases and the resolution becomes finer. If there are no aberrations, f/0.95 has the potential to achieve high resolution by itself.

5 What is Noct

Noct is derived from the word "Nocturne", and is named after the AI Noct Nikkor 58mm f/1.2 (hereinafter, AI Noct), released in 1977[2]. The AI Noct was commercialized as a lens suitable for night photography; a lens for night photography must satisfy the following two points: First, it must have a "bright large-aperture" that can ensure a higher shutter speed with appropriate ISO sensitivity. Second, "a point light source must be projected as a point (point image reproducibility)", which is essential. As an F mount, AI Noct has a brightness limit of f/1.2, and it has been devised to improve point image reproducibility by overcoming the sagittal coma flare that occurs in many large-aperture lenses. The NIKKOR Z 58mm f/0.95 S Noct (hereinafter, Z Noct) was also named Noct because it has a larger aperture, f/0.95, made possible with the Z mount, and can realize a more ideal point image reproducibility than the earlier version.

However, the reproducibility of ideal point image is possible due to the lens having "no aberration". This is because it can capture a dot as a dot without the slightest of deviation. Further, it also enables the realization of an ideal blur. With no aberration, there exists no peculiarities in the front and rear blurs; the blurs are uniform and continuous. This is the purpose of Z Noct, with which actual shooting gives a strong impression of the three-dimensionality of the subject.

In the development of Z Noct, various restrictions and common practices that are inherent in the optical design are eliminated so that the optical specifications and performance are satisfied. Therefore, its size, price and performance are amazing.

6 Axis of Z Noct – Double Gauss Type

The optical system of Z Noct can be approximately divided into three parts, namely the front group, the master group, and the rear group. The front and rear groups are f/0.95, and they form an auxiliary optical system that provides the performance suitable for the new Noct. The master group, which is the core, is based on a famous optical system called the "double Gauss-type (hereinafter, Gauss-type)". Since the Gauss-type is often used in large-aperture standard lenses, AI Noct is also a Gauss-type lens, similar to many others. Further, the f/0.95 lenses released by other companies are also based on the Gauss-type. The characteristics of Gauss-type include good symmetry, excellent aberration correction, and high flatness of the image plane, which are the capabilities required for the point image reproducibility of Noct.

Symmetry is an important factor for aberration correction. In Z Noct, the general framework of the front, master and rear groups have a symmetrical structure, making the optical system more powerful in terms of aberration correction. Further, to achieve the target high-performance, the design of the Gauss-type Z Noct is different from the usual one in the way aberrations are corrected.

As its name suggests, the Gauss-type optical system is comprised of two Gaussian objective lenses, which can be schematically written as "convex-concave-concave-convex". A more general form is the six-element structure, "convex-convex-concave-concave-convex-convex". Although adopted in many large-aperture standard lenses, the biggest drawback of the Gauss-type is the aberration called sagittal coma flare, which requires some ingenuity. Since the Gauss-type has powerful concave surfaces facing each other, it can strongly correct spherical and coma aberrations, Petzval sum, and so on. In layman's terms, it is a method of "controlling poison with poison", and in exchange for correcting the lower order aberrations, sagittal coma flares of higher order aberrations occur. The means of avoiding this powerful concave surface include "increasing the number of lens elements", "increasing the refractive index", and "making the surface aspherical".

In AI Noct, the sagittal coma flare is improved mainly by "increasing the refractive index" and "making the surface aspherical"[2]. The former is a very useful method because the correction effect of all five Seidal aberrations can be obtained with a little change in the shape of the glass material. On the other hand, there is a tendency of an increase in the cost of glass material and worsening of chromatic aberrations. With aspherical surface, the aberration to be corrected changes depending on the location where the optical system is used. In AI Noct, by using a front lens with the largest luminous flux diameter, spherical and coma aberrations, as well as sagittal coma flares are effectively corrected. The disadvantage of aspherical lenses is its costly mass production, where the difficulty level depends on the size and required accuracy of the aspherical lens. Moreover, since many aspherical lenses are made by a glass molding method, there are also restrictions on the glass materials that can be used.

Moreover, Z Noct utilizes the "increase in the number of lens elements" in the front and rear groups to achieve high performance at f/0.95. Increasing the number of lens elements is an orthodox means to avoid the occurrence of aberration as much as possible by guiding the light rays straight without much bending. It is for the same reason that many existing large-aperture standard lenses also have optical systems where multiple lens elements are added to the Gauss-type. The unique feature of Z Noct is that the configurations added at the front and back are independent. This configuration has been made possible by making full use of the large aperture short flange back of the Z mount.

To achieve high performance without compromise, it is necessary to compensate for the deterioration due to chromatic aberration, which is a disadvantage of "increasing the refractive index". The influence of chromatic aberration is high in the master group and low in the front and rear groups. Therefore, high refractive index glass materials are used for the front and rear lens groups, giving priority to the correction of the five Seidal aberrations, while low refractive index and low dispersion ED lens elements are frequently adopted for the Gauss-type master group.

Although corrections of spherical aberrations and sagittal coma flares become difficult when using low refractive index lens elements for the Gauss-type, three ideas have been implemented. The first is, reducing the load of aberration correction on the master group by adding the front and rear groups to share the aberration. The second is, using aspherical surfaces in each of the three groups to suppress the aberration amount occurring in each group, thereby suppressing the higher order aberrations at the same time. This is a usage opposite to that of AI Noct. The third is, making the cemented lens elements of the Gauss-type master group into old achromatic cemented lens elements, which is advantageous for spherical and coma aberration correction. (Old achromatic cemented lens: Cementing of lens elements where the concave lens has a higher refractive index than the convex lens. The opposite is called the new achromatic cemented lens).

Even with a normal Gauss-type lens, if an extra-low dispersion lens (ED lens) is used with an aspherical surface or an old achromatic cemented lens element, the same effect can be obtained. However, one thing that cannot be corrected is the Petzval sum, the cornerstone of field curvature, which is determined by the refractive power and refractive index of the surface. In many camera lenses, as the refractive index of the convex lens is high and that of the concave lens is low, the presence of a powerful concave surface is necessary for correction. The presence of ED lens for improving chromatic aberration, the presence of an old achromatic cemented lens for the correction of spherical aberration, and the relaxation in the powerful concave surface for the correction of sagittal coma flare contribute to increase in the Petzval sum, causing the occurrence of field curvature, and thus, impairing the image reproducibility. Therefore, in addition to having the front and rear groups share the aberration, Z Noct uses a new achromatic junction to eliminate this Petzval sum; it also has a strong concave surface.

Thus, at f/0.95, Z Noct overcomes sagittal coma flare, the weak point of Gauss-type, while improving chromatic aberration and point image reproducibility, and becomes the ultra-large aperture lens with the highest performance in history.

7 Ground Aspherical Surface

There are two new optical technologies that support the astonishing performance and specifications of Z Noct. One is the ground aspherical surface. Although the technology itself is not new, Nikon has updated it into a unique precision machining technology with high accuracy.

Recently the performance of camera lenses has improved remarkably, and aspherical surfaces have become an indispensable technology. Many camera lenses use aspherical surfaces, most of which are molded glass aspherical surfaces. The reason why ground aspherical surfaces are not often adopted is its complex mass production process due to the processing method. However, since the ground aspherical surface is very useful to improve the performance, it has become an indispensable part of Z Noct.

The advantage of the ground aspherical surface is its high degree of freedom in selecting glass materials. Restriction in the glass material corresponds to constraints in the control of light rays, and there are optical disadvantages such as failure to meet the performance goals. Because it is made by a thermoforming process, a molded glass aspherical surface can be created only with the glass molding materials. Meanwhile, as the ground aspherical surface, is made by a grinding process, any glass material where spherical surface processing is possible, can be adopted. Optically attractive glass materials that are not found in molding materials have high refractive index, as well as high and anomalous dispersion. The term “anomalous dispersion” used here includes not only the ED lenses having positive anomalous dispersion, but also the glass materials having negative anomalous dispersion. Although it is easy to understand that such characteristic glass materials can be made aspherical, the fact that other glass materials can be made similar is also important. The reason is, although camera lenses tend to have combinations and arrangements of glass materials for achromatism, regardless of those arrangements, aspherical lens elements are the most effective. Since high refractive index and chromatic aberration are key in Z Noct, it was necessary to make a glass material having a high refractive index and low dispersion as aspherical as possible. Further, it is also possible to achieve higher precision than with a molded glass aspherical surface. During the thermal process, various deformations and alterations occur. On the other hand, a ground aspherical surface is determined only by the machining accuracy. Although the ground aspherical lens element of Z Noct has a large lens diameter of f/0.95, it has high surface accuracy of submicron level (about 1/200th of the thickness of hair) over its entire surface. Z Noct is able to achieve high performance because of the presence of ground aspherical surface technology that enables the stable production of large lenses with high accuracy.

8 ARNEO Coat

Another new technology that supports the high performance and specifications of Z Noct is the newly developed anti-reflection coating, “ARNEO coat”. The characteristic of ARNEO coat is that it exerts a high suppression effect on the reflection of light that is incident perpendicular to the lens surface[3] (Fig. 3).

The coating technology suppresses ghosts and flares by preventing reflection on the lens surface. If there is no coating, the light to be imaged will be blocked by reflection. Meanwhile, the reflected and incident light that would not have reached the imaging surface if it were the original optical path, will reach the imaging surface while being reflected multiple times inside the lens barrel, and be captured as the image. Some of the reflected light will diverge and appear as flares, whereas others converge and appear as ghosts. Naturally, if more light is taken in, together with Z Noct, ghosts and flares are more likely to appear.

As a result of pursuing high optical performance, Z Noct has a shape that guides light in a natural manner. In other words, this means that the incidence angle on the lens is often nearly vertical. Thus, without the ARNEO coat, it is impossible to obtain higher performance, as the configuration that guides the light in an unaffected manner must be compromised.

Since normal incidence is not limited to Z Noct, but can occur in any setting, ARNEO coat is expected to benefit many lenses. It can be said that by combining NIKKOR lens with Nano Crystal coating, which is strong against oblique incidence, omnidirectional cover has become possible.

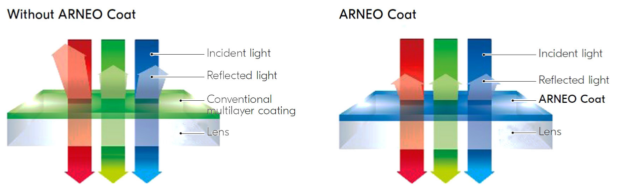

Fig. 3　Difference between conventional coat and ARNEO coat.

9 Manual Focus Mechanism

First, we will explain the reason why Z Noct is a manual focus lens.

The maximum aperture f/0.95 results in very shallow depth of field making focusing difficult. For example, when photographing a person obliquely with the eye as the focusing point, in the case of extremely shallow field depth of f/0.95, depending on whether you focus on the corner of the eye, pupil or the inner corner of the eye, the impression of the work may vary. In the case where a majority of the eye fits inside the focus-aid frame of the camera, the focus position can be determined only by the photographer. To maximize the optical performance of Z Noct, manual focus is considered to be the best.

There is also another reason. In reality, the focus lens group is so heavy that a practical autofocus mechanism cannot be constructed from the viewpoint of product size and focus accuracy.

For these reasons, when designing a manual focus mechanism, two main points must be considered: ① - The photographer must be able to focus as he/she desires, even with an extremely shallow field depth of the maximum aperture f/0.95, in other words, the operation resolution must be ensured. ② - Even with an extremely heavy focus lens, the photographer must be able to operate it easily, and the feel of the focus ring must be comfortable. In order to realize these two points, it was necessary to increase the rotation angle of the focus ring to reduce the lead angle of the helicoid mechanism used for driving the focus lens.

Therefore, to determine the required degree of operation resolution, the rotational operation that can perform the minimum movement was verified. Based on verifications of multiple people, from beginners to heavy camera users within our company, the amount of rotational operation that can move the focus ring at a minimum, regardless of the skill of the photographer, was confirmed to be about 0.5 mm in circumference. The change in focus for the amount of rotation operation of the focus ring was set to about 20 μm in terms of the image plane. This is based on the assumption that focusing by the photographer will not be stopped by continuous rotation operation, but rather by pitch operation, in which the focus ring is rotated gradually.

Based on this operation resolution, to absorb the focus shift due to the focus ring movement from infinity to the shortest shooting distance, temperature changes, manufacturing errors, etc., the amount of extreme rotation in both the infinity side and the near-side was secured. Consequently, the focus ring rotation angle was close to 360 degrees.

The other point was about the feel of the operation. It was assumed that with the above-mentioned focus ring rotation angle, anyone would feel the light operational torque. If the operation torque is too light, it may cause the camera to rotate more than what is intended by the photographer, and thus, proper focusing may fail to be performed. Moreover, for manual focus, a graceful feel with a certain weight tends to be preferred.

In Z Noct, the focus ring diameter is as large as ϕ102 mm. Therefore, for example, in order to obtain the same feel of operation (= tangential force) as a focus ring of ϕ70 mm, it is necessary to use an operating torque proportionate to the focus ring radius, which is about 1.5 times. Usually, a large amount of grease is applied to the helicoid part to give a solid and graceful feel of operation. However, with a lens of this diameter, increasing the torque only with the grease amount is challenging, it is dealt with by providing a mechanism that applies a torque load by pressing the two parts that rotate inside the focus lens drive mechanism toward the optical axis. While ensuring a moderate operating torque by pressing in the direction of the optical axis, compared to conventional products, a graceful and smooth operation is realized by adjusting the grease amount and increasing the roughness of the sliding surface of the helicoid. Because a backlash removal effect due to the pressing is also obtained, the tracking delay of the focus lens with respect to the focus ring operation is eliminated, enabling precise focusing even during reversing operations.

10 Design

The design keyword of Z Noct that aims to express the highest optical performance and quality is "craftsmanship". Because all the external parts are machined in metal and carefully finished one-by-one, it has both a high-quality texture and high part precision to maintain performance (Fig. 4). In addition, engraving the characters "Noct" in cursive style gives a special feeling that it has been made by a craftsman (Fig. 5)[4].

Fig. 4　Cut of cross-section.

The design of the functional parts can be appreciated as the core concept of Z system design that emphasizes operability.

In order to improve the finger grip, the focus ring has a wider pitch (perimeter) than the focus ring knurls of other NIKKOR Z lenses. If the pitch is made the same as that of other products, it will become slippery due to the large ring diameter. Further, by making the unevenness of the knurling clear, it was possible to give a more vivid impression. The

Fig. 5　"Noct" character engraving process.

tripod mount is designed in such a way that it does not interfere with the operation even when shooting handheld. Since it is better to have only a small number of components partially protruding from the lens barrel, the tripod mount is made as close to the lens barrel as possible, with the size also reduced. The tripod mount is designed such that it cannot be detached, and the locking mechanism was also eliminated. By doing this, it was possible to realize full functionality and operability, without disturbing the shape of the lens body. Although the ring width looks thin at first glance, sufficient rigidity is assured through the thickness of materials.

The lens hood of Z Noct has a round shape. By making the outer diameter the same as that of the lens barrel and mounting it on the tip of the focus ring, the lens hood itself is designed in such a way that it gives a sense of unity, as if it were a part of the lens barrel (Fig. 6). It gives a feeling of better balance between the total length and the outer diameter of the lens when the hood is attached. In addition to the lens hood's original function of blocking light from outside of the view angle, the role of protecting the lens has also been considered. Although the focus lens of Z Noct is of a type that extends forward as it is focused, the lens hood is mounted on the tip of the focus ring and not on the tip of the lens as mentioned earlier, it covers the extending lens without moving back and forth; even in the most extended state, the lens does not protrude from the lens hood. This prevents accidental bumping of the extended lens tip. Moreover, rubber is installed on the tip of the lens hood to ensure the impact is less likely to be transmitted to the entire lens barrel during a hit. Further, it is designed such that even when placed face down, the lens hood does not slip easily or damage the other side. Such design concept is followed not only in Z Noct but also in all NIKKOR Z lenses.

Fig. 6　Product appearance with hood attached[5].

11 Summary

NIKKOR Z 58mm f/0.95 S Noct is a product made with thorough consideration of functionality, operability, and design, as well as the optical performance. Although it is large in size and heavy, making the manual lens difficult to shoot with, we hope you will greatly enjoy its performance and functions, and appreciate the joy of shooting. We wish that with the high-performance world of f/0.95, new visual expressions will be created.

By developing products that exceed customer expectations, we will continue to strive for the development of Nikon Z mount system, together with the development of camera and visual culture.

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