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Analysis of Optical Characteristics of Oil Immersion Lens in Aqueous Environment

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액상유체 오일 이멀전 렌즈의 광학 물성치 해석

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ABSTRACT

The oil immersion method can be used to create objective lenses with long working distances without sacrificing the focusing resolution for laser processing. In this study, a space in which air or oil can be filled was formed in the middle of a lens for analyzing the optical properties of a liquid-oil immersion lens. As the refractive media, air and oils of different refractive index values (1.2 and 1.5, respectively) were used. A simulation was conducted in the ZEMAX software environment using the ray-tracing technique, and the performance of the oil immersion lens was verified by determining its image distortion and focal length (FL) in each medium. In the case of air, the calculated FL was 0.813 mm, whereas the imaged FLs were 1.594 mm and 8.126 mm when the refraction indices were 1.2 and 1.5, respectively. The FL of an oil immersion lens could be increased considerably. In terms of image distortion, the oil immersion lens exhibited little distortion at the center in all cases, but different degrees of image distortion were observed at different points away from the center depending on the refraction index degree.

Keywords: Laser Scattering(레이저 산란), Optical Properties(광학물성치), Oil Emersion Lens(오일이멀전 렌즈), Ray Tracing(광선추적), Lens Design(렌즈설계)

1. Introduction

The optical resolution of a microscope can be increased by adjusting the curvature of the objective lens or by stacking multiple lenses. In this way, one can focus light onto a spot smaller than one would be able to in free space to enhance the spatial resolution, which can be useful in microscopy, spectroscopy, Fresnel lens, and lithography applications[1-2]. However, when the resolution of the objective lens is limited, apart from the aforementioned methods, the oil immersion method can be used to increase its resolution[3-4].

In general, by using an oil with a refractive index of n = 1.518, which is close to the refractive index of glass, one can obtain high-resolution images.

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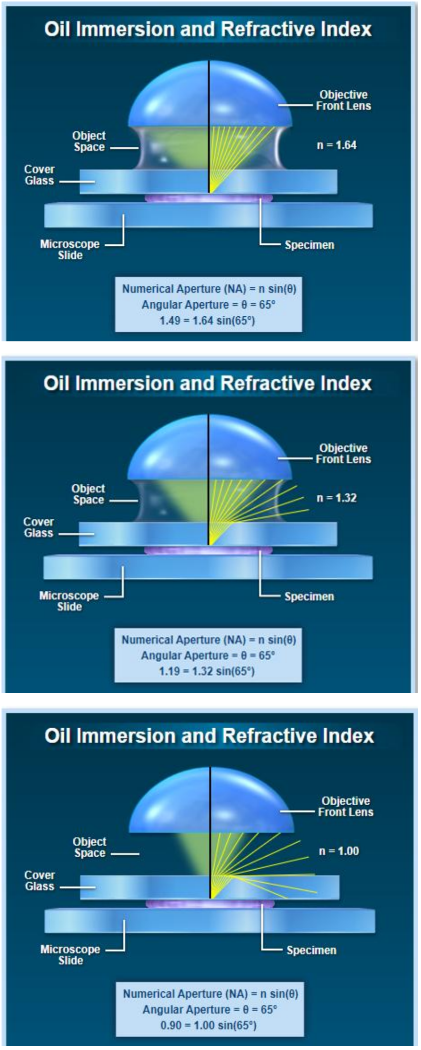


Fig. 1 Characteristics of Oil Immersion Lens[6)]

Fig. 1 shows an example of the image diffusion that occurs when the refractive index of an oil immersion lens changes.

An oil immersion lens can be used as an objective lens (focusing lens) for laser processing. In general, when the optical resolution of the objective lens is high, the size of the focal point can be reduced, and precision processing can be performed. However, the lens can be damaged by the debris generated during processing because of the proximity between the lens and the workpiece. Therefore, it is necessary to design a suitable combination of lenses by adjusting the working distance and resolution, and to this end, an analytical understanding is necessary.

This paper describes the results of a method for interpreting the optical properties of oil immersion lens by using the ray-tracing method in a commercial simulation software.

2. Theory and Simulation

All chromatic and spherical aberrations of a lens must be calculated to reconstruct and image the light scattered by successive lenses[5]. The key variables are the opening angle and refractive indices of the lenses. Based on the resolution of the objective lens, a minimum distance d (working distance or standoff) between two objects is required.

At distances shorter than d, the two objects appear as a single object when viewed through the microscope, the higher resolution image can be obtained. In general, the resolution of a lens can be calculated as

$$d = \frac{\lambda}{2NA} \qquad (1)$$

Where d denotes the working distance, λ is the wavelength of light, and NA is the Numerical Aperture of the lens. According to Equation (1), a large NA is required at the minimum distance (d) to achieve a high resolution, and the NA increases in proportion to the refractive index. Theoretically, if the gap d is filled with air, the NA value cannot be greater than 1, but if the space is filled with oil, a value greater than 1 can be realized because the refractive index of some oils is greater than 1.

The refractive index of natural oils used in commercial applications is approximately 1.516

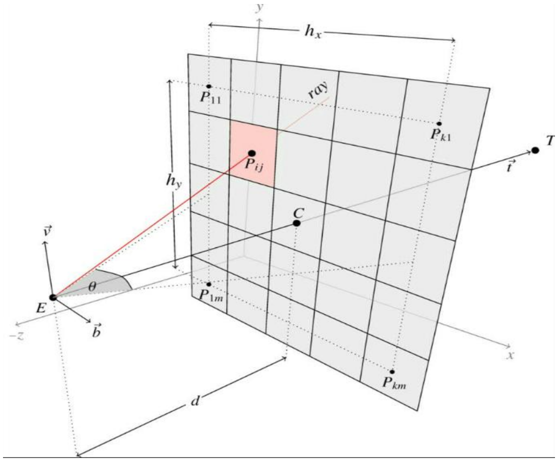


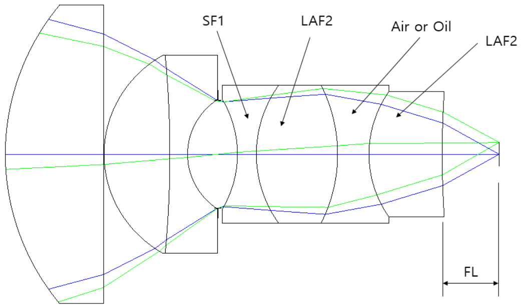
Fig. 2 Theory of ray tracing[7]

(cedar oil), but such oils deteriorate and damage the lens. Recently, synthetic immersion oils have been used in commercial microscopes, and these oils have NA values of up to 1.6.

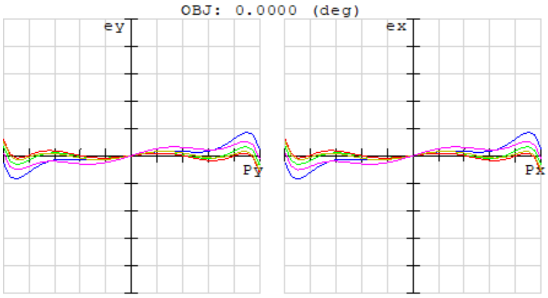
The optical ray-tracing technique assumes that a laser is considered as a particle rather than a wave and that it is refracted or reflected according to the refractive index based on Snell's law. As shown in Fig. 2, when each light emitting from the laser source E is emitted, each pixel defined as P in an imaginary region (x-y plane) at a distance (d) can defined.

The emitted light which passes between P_{ij} and E, a vector R is defined as $\overrightarrow{R_{ij}} = P_{ij} - E$, the path of ray can be calculated based on the given information.

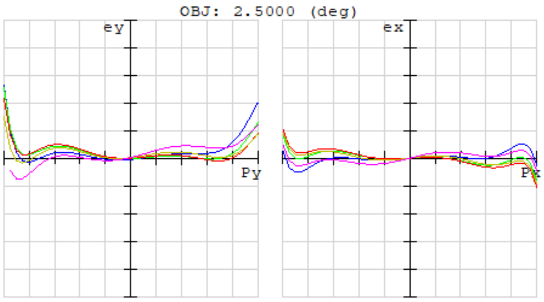
Such ray tracing involves large amounts of repetitive computation, and therefore, these computations should be performed using a commercially available ray-tracing software program (ex, ZEMAX). The oil immersion lens used in this study is shown in Fig. 3(a). A space for filling air or oil was formed in the central region of the lens, and the resolution and focal length (FL) of the lens were analyzed by filling the aforementioned space with various media.



(a) Array of lens



(b) Ray fan plot for 0 deg (grid unit: 40㎛)



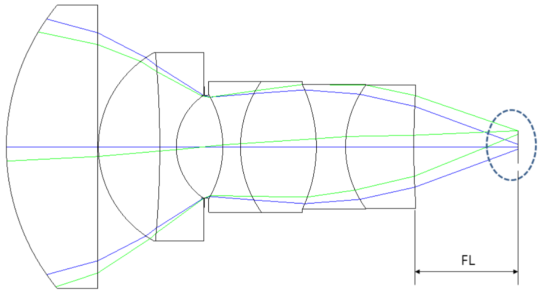
(c) Ray fan plot for 2.5 deg (grid unit: 40㎛)

Fig. 3 Characteristics of Oil Immersion Lens with Air refill (Index of refraction[1])

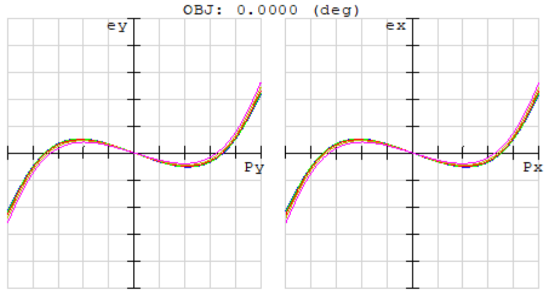
3. Results

The results of simulation are summarized in Fig. 3 to Fig. 5 for the different index of refraction cases.

Fig. 3 shows the image aberration and FL calculated when air was filled between the lenses. As shown in Fig. 3(a), the calculated FL is 0.813



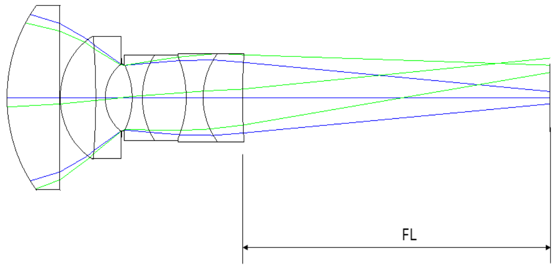
(a) Array of lens for oil immersion



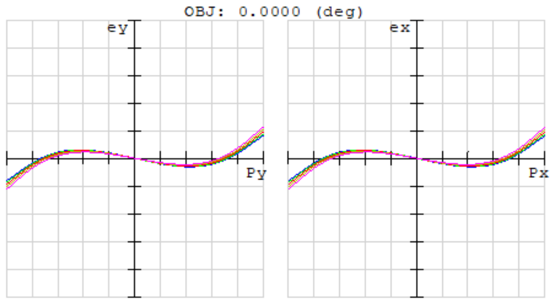
(b) Ray fan plot for 0 deg (grid unit: 400㎛)

(c) Ray fan plot for 2.5 deg (grid unit: 400㎛)

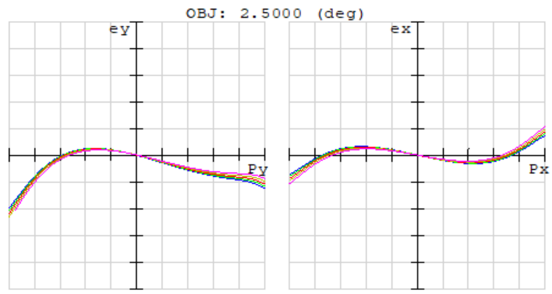
Fig. 4 Characteristics of Oil Immersion Lens with oil refill (Index of refraction 1.2)



(a) Array of lens for oil immersion



(b) Ray fan plot for 0 deg (grid unit: 1.2mm)



(c) Ray fan plot for 2.5 deg (grid unit: 1.2mm)

Fig. 5 Characteristics of Oil Immersion Lens with oil refill (Index of refraction 1.5)

mm. The ray fan plot, which represents focus or image distortion, indicated that almost no distortion occurred at the center when the angle of incidence was 0°.

By contrast, the maximum distortion of 40㎛ occurred in a region located approximately 200㎛ from the center. When the angle of incidence was 2.5°, image distortion of up to 20㎛ occurred in the region located 120㎛ from the center of the optical path, and severe distortion occurred in the region located 200㎛ away from the center.

Fig. 4 shows the calculated image distortion and FL when the gap between the lenses was filled with oil of refractive index 1.2. As in Fig. 4 (a), the calculated FL was 1.594mm, and the ray fan plot indicated almost no distortion at the center when the angle of incidence was 0°.

Image distortion of up to 200㎛ occurred at 800 ㎛ from the center, and severe distortion occurred at

Table 1 Property comparison of samples

Index of Refraction	FL(mm)	Abb.@ 2 grid (㎛)	
		0°	2.5°
1.0	0.813	~0	20
1.2	1.594	~0	200
1.3	2.345	~0	200
1.5	8.126	~0	400

2000㎛ from the center. Similar results were obtained when the angle of incidence was 2.5°.

Fig. 5 shows the calculated image distortion and FL when the gap between the two lenses was filled with oil having a maximum refractive index of 1.5. Except for the magnitude of image distortion, the results obtained were similar to those obtained in case of the oil with the refractive index of 1.2.

As in Fig. 5(a), the calculated FL was 8.126 mm. The ray fan plot indicated almost no distortion at the center when the angle of incidence was 0°, but image distortion of up to 600㎛ occurred at a distance of 2.4mm from the center. Therefore, it cannot function as a focusing lens.

The results of simulation is summarized in Table 1 where focal length and aberrations of lens at the second grid are calculated.

4. Conclusions

In this study, a space to fill air or oil was formed in the middle of a lens for analyzing the optical properties of the resulting oil immersion lens. As the media, air and oils of different refractive index values (1.2 and 1.5) were used. Simulation was performed using ZEMAX, a commercially available software program, and the ray-tracing technique, and the performance of the oil immersion lens was verified by computing the image distortion and FL of the lens for each medium.

In the case of air, the calculated FL of the lens was 0.813mm. The image FL was 1.594mm when the gap in the lens was filled with oil of refractive index 1.2. The FL was 8.126mm when the gap in the lens was filled with oil having a maximum refractive index of 1.5. In conclusion, the FL of an oil immersion lens can be increased considerably, which is very advantageous for laser processing.

In terms of image distortion, there was little distortion at the center in all cases, but different degrees of distortion were observed at various points away from the center depending on the degree of index of refraction.

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REFERENCES

1. Chen, W. T., Zhu A. Y., Khorasaninejad, M., Shi, Z., Sanjeev, V. and Capasso, F., “Immersion Meta-Lenses at Visible Wavelengths for Nanoscale Imaging,” Nano Letters, Vol. 17, No. 5, pp. 3188-3194, 2017.
2. Koshelev, A., Calafiore, G., Piña-Hernandez, C., Allen, F., Dhuey, S., Sassolini, S., Wong, E., Lum, P., Munechika, K. and Cabrini, S., "High Refractive Index Fresnel Lens on a Fiber Fabricated by Nanoimprint Lithography for Immersion Applications," Optics Letters, Vol. 41, pp. 3423-3426, 2016.
3. Hwang, K. H., Wu, H. F., Choi, W. S. and Kang, M. C., “Comparative Study on Ablation Characteristics of Ti-6Al-4V Alloy and Ti_2AlN Bulks Irradiated by Femto-second Laser,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 7, pp. 90-96, 2019.
4. Choi, H., “Laser Beam Scattering Analysis in Aqueous Environments,” Journal of the Korean

Society of Manufacturing Process Engineers, Vol. 18, No. 2, pp. 91-95, 2019.

5. Choi, H., “Analysis of Heat Transfer by Various Laser Beam Patterns in Laser Material Process,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 5, pp. 37-44, 2018.
6. Olympus life science web resource, https://www.olympus-lifescience.com/en/microscope-resource/
7. https://en.wikipedia.org/wiki/Oil_immersion