A Systematic View of Microscope Objective Design

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Abstract. The correction of modern microscope objectives is not usually discussed in literature. We have reported a system review and summarized the design principles in a series of papers in 2019 [1-3]. Here we are introducing the systematic view of microscope objective design with an extension of the database till 2021. Furthermore, a systematic synthesis approach aided by AI will also be discussed.

1 Introduction

As the most well-known high numerical aperture (NA) optical system, the light microscope objective has been deeply developed in the past century and utilised in various applications. Owing to a collection of 477 relevant US, JP, DE, and WO patents with purely refractive microscope objectives from 1926 to 2021, the application-oriented development history can be clearly understood. An overview is given in Figure 1.

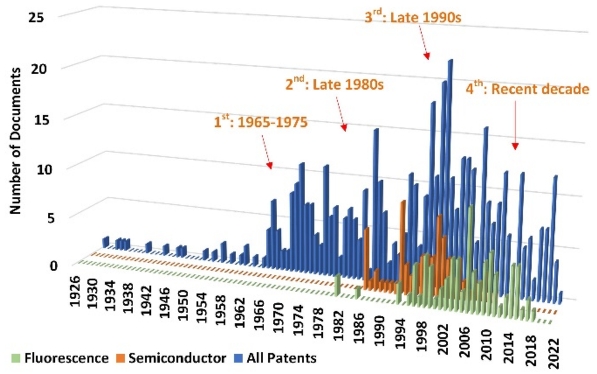

Fig. 1. Number of modern microscope objective patents from 1926 to 2021 with four peaks of patenting activities.

Based on the patent database, an objective database is constructed with 519 entries with different structures. To fairly compare the material selection and system complexity, the constructed systems must have a colour correction covering the visible spectrum (VIS).

The systems cover a full range of magnification from 0.5x to 250x and a full range of NA from 0.025 to 1.70. According to their magnification and NA, the systems can be further classified into six zones corresponding to the etendue and different level of correction, demonstrated in Figure 2:

- Zone 1: typical ach/apochromate two-group systems
- Zone 2: typical Plan-ach/apochromate clear-three-group systems
- Zone 3: novel three-group systems with special correction lens modules
- Zone 4: systems with extremely high NA or etendue, which sacrifice other system parameters, such as parfocal length and immersion liquid type
- Zone 5: very low magnification parfocal telecentric systems
- Zone 6: very high magnification systems

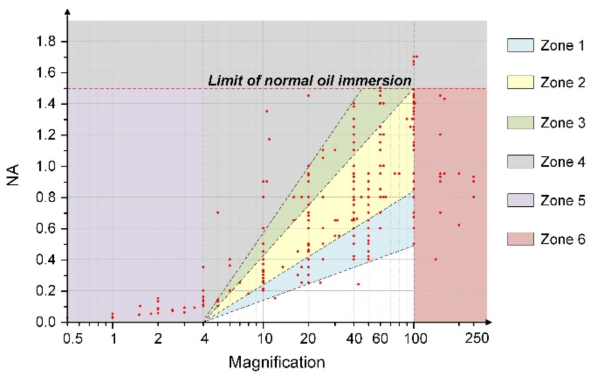

Fig. 2. 6-zone classification of microscope objectives based on etendue.

Focusing on each of the zones, the system structures can be carefully compared by analysing the aberration behaviours of each lens group, thus summarising the lens modules utilised in conventional designs.

2 Conventional Design

We are summarising the conventional design principles of the microscope objective design, which are valid in more than 80% of corresponding systems. They can be classified into three categories: optical power distribution, material selection and lens structures. The combination of

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a material selection and lens structure is regarded as a lens module.

Among the six zones of the microscope objective classification based on etendue, the optical power distribution has four basic types. Selecting one power distribution basically determines one branch of systems in the solution space. The objectives can then be divided into two or three structural/functional groups. 10 lens modules in the front group, 9 lens modules in the middle group and 10 lens modules in the rear group are summarized as the design principles. By inserting the lens modules locally, the microscope objective lens can be evolved from a low-etendue simple structure with poor colour and field correction to a high-etendue sophisticated structure with high correction level. An example is demonstrated in Figure 3.

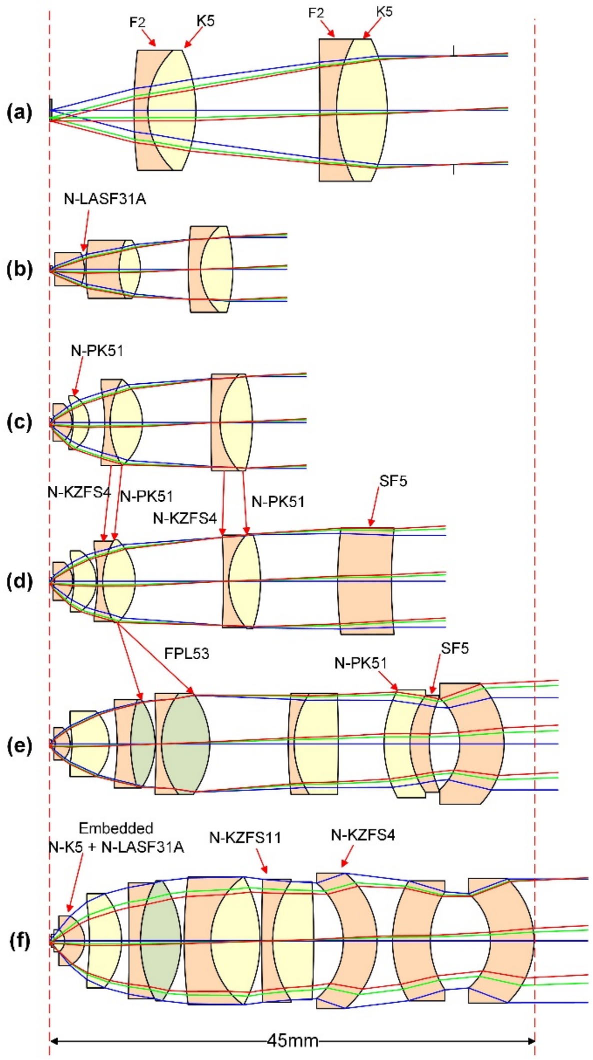

Fig. 3. Full process of a 40x/1.20 SF20 oil-immersion objective synthesis. (a) Step I 10x/0.25 Achromate objective. (b) Step II 40x/0.60 Achromate objective. (c) Step III 40x/0.85 Achromate objective. (d) Step IV 40x/0.85 Plan-semiapo objective. (e) Step V 40x/0.85 Plan-apochromate CORR objective. (f) Final design 40x/1.20 Plan-apochromate objective.

3 Systematic Synthesis with AI

Although dividing the microscope objectives into lens modules provides a systematic view of the lens design, to insert the modules locally for synthesis still requires the experience of optical designers and it is not sufficient to show the overview of the whole solution space.

Since it is difficult to convert these empirical models into mathematical models for direct optimization, a more promising method is to develop a deep learning-enabled lens design extrapolation approach that trains a deep neural network (DNN) model, which takes the objective database as a training dataset.

Recently, selecting 34 systems from the database with object space numerical aperture 0.35 < NA < 0.45 and half image space field angle 2.5° < HFOV < 4.5° as the training domain, we reported such a tool that can both interpolate and extrapolate the solution space of a 20x/0.40 Plan-apochromate solo-corrected infinite-conjugate objective [4]. All the three possible basic structures with distinctive power distributions are reproduced: Lister two-group, double-Gauss and retrofocus. The lens modules are also well exploited in the examples.

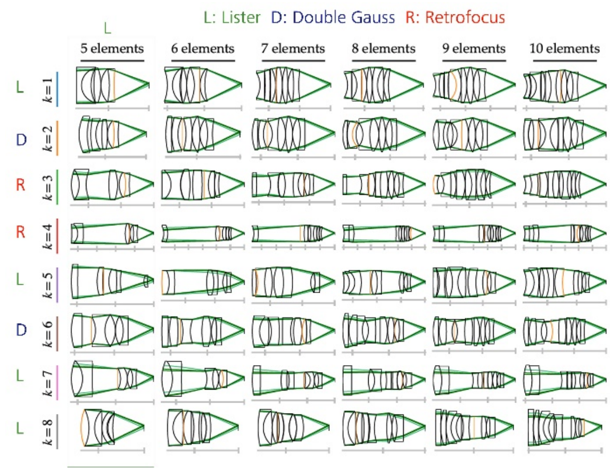

Fig. 4. Subset of designs inferred from all branches of the training model for the 20x/0.40 Plan-apochromate objective.

The tool can generate initial systems for a specific task. With its help, optical designers can have a better view of the solution space to decide whether it is necessary to further increase the number of elements.

References

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