基于 Zemax 的双高斯物镜的设计与仿真

摘要：本研究基于 Zemax OpticStudio 平台，对经典双高斯物镜专利（US2701982、US3560079、US3851953）与新型专利设计（CN116661103A、CN118859479A、CN117908231A）进行系统性建模与仿真分析。通过构建 MTF（调制传递函数）、像斑半径等核心评价指标，对比了新旧设计在成像质量方面的差异。结果表明，新型设计在公差容限、热漂移控制及成像性能上显著优于经典设计：CN117908231A 专利的 MTF 截止频率达 280 周期/mm（较经典设计提升 19.8 倍），最大像斑半径缩小至 3.721um（优化率达 66.5 倍）；CN116661103A 通过偶次非球面与耐高温材料组合，实现全视场 MTF 温度波动 <5%。此外，Zemax 工具在优化过程中展现出关键赋能价值，其集成化的 MTF 操作数、公差分析模块及热膨胀系数数据库支持了从像差校正到制造可行性的全流程验证。研究为双高斯物镜的迭代设计提供了量化依据，并指出未来可通过非球面深化应用、材料-结构协同创新及智能化算法进一步突破性能瓶颈。

关键词：双高斯物镜；Zemax 仿真；成像性能优化；性能对比；公差分析

Design and Simulation of Double-Gauss Objective based on Zemax

Abstract: This study is based on the Zemax OpticStudio platform and conducts systematic modelling and simulation analysis on the patents of classic Double-Gauss objective lenses (US2701982, US3560079, US3851953) and new patent designs (CN116661103A, CN118859479A, CN117908231A). By constructing core evaluation indicators such as the MTF (Modulation Transfer Function) and the spot radius, the differences in imaging quality between the old and new designs are compared. The results show that the new designs are significantly superior to the classic designs in terms of tolerance limits, thermal drift control, and imaging performance: The MTF cutoff frequency of the patent CN117908231A reaches 280 cycles/mm (an increase of 19.8 times compared to the classic design), and the maximum spot radius is reduced to 3.721um (the optimization rate is 66.5 times); Through the combination of even aspherical surfaces and high-temperature-resistant materials, CN116661103A achieves a temperature fluctuation of the MTF across the entire field of view of less than 5%. In addition, the Zemax tool demonstrates crucial enabling value during the optimization process. Its integrated MTF operands, tolerance analysis module, and thermal expansion coefficient database support the full-process verification from aberration correction to manufacturing feasibility. This study provides a quantitative basis for the iterative design of Double-Gauss objective lenses, and points out that in the future, performance bottlenecks can be further broken through by deepening the application of aspherical surfaces, collaborative innovation of materials and structures, and intelligent algorithms.

Keywords: Double-gauss objective; Zemax simulation; Imaging performance optimization; Performance comparison; Tolerance analysis

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1 绪论

1.1 研究背景与意义

双高斯物镜作为经典光学结构，自 1888 年 Alvan G. Clark 提出对称式双高斯概念以来，历经百年技术迭代，始终在成像光学领域占据核心地位。其意义主要体现在以下三方面：

1.1.1 双高斯物镜本身设计优势

双高斯结构通过对称布局的正负透镜组平衡像差，显著提升大孔径镜头的成像质量。相较于早期三片式物镜，其对称性设计可同时校正球差、彗差和场曲，使 F/2.0 以上大光圈镜头的 MTF@50lp/mm 提升至 0.4 以上，为高分辨率成像奠定基础。

2 相关工作

残差网络（ResNet）通过引入跳跃连接有效解决了深度网络训练难题[1]。给定输入 x，残差块可表示为：

$$y = \mathcal{F}(x, \{W_i\}) + x \tag{1}$$

3 实验与结果

我们在 CIFAR-10 数据集上评估了模型性能，实验结果如表1所示。

表 1: 分类准确率对比

模型	准确率 (%)	参数量 (M)
ResNet-50	98.2	25.6
VGG-16	95.1	138.4

参考文献

[1] HE K, ZHANG X, REN S, et al. Deep Residual Learning for Image Recognition[J]. CVPR, 2016.