Color corrected optical relay system for photolithographic synthesis of DNA

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Photolithographic synthesis of nucleic acid microarrays uses a 1:1 imaging of a digital micromirror device (DMD) at wavelengths around 365 nm. A catadioptric relay system with increased numerical aperture of 0.12 has been developed as an alternative to an Offner relay. The new design is corrected for all third order aberrations including color using only spherical surfaces and a single glass type.

1 Introduction

Synthetic creation of nucleic acids (e.g. DNA, mRNA) provides a means for accelerated research and engineering of biological materials as e.g. employed in genome analysis and RNA therapeutics. The creation of so-called DNA-microarrays can be efficiently performed on a large scale using maskless array synthesis (MAS). A digital mask is created by a digital micromirror device (DMD) which is illuminated with UV light and subsequently imaged onto reacting target chemicals with an optical relay system as illustrated in Figure 1 [1].

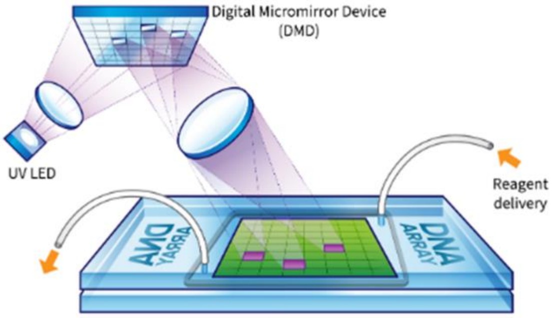

Fig. 1 *Principle of Maskless Array Synthesis*

One of the main optical elements of the system is the optical relay unit imaging the DMD light pattern onto the target chemical cell. High optical resolution, hence large numerical aperture is desired to employ DMD devices with the largest number of micromirrors giving the largest number of individual nucleic acid samples as possible to increase efficiency during nucleic analysis.

2 Mirror Relay Systems

Hitherto, Offner relay systems have been used to realize the 1:1 imaging from DMD to the DNA array. The original Offner relay design features two concentric mirrors and has the stop at the secondary mirror giving a telecentric setup [2]. In a previous version of the MAS the Offner relay as shown in Figure 2 (top) has been used. It has a numerical aperture of 0.08 and a sufficiently large field for smaller DMDs. Using a DMD with increased number of micromirrors and 20 mm x 14 mm size, Figure 2 shows that the polychromatic Strehl-ratio (for equally weighted wavelengths 345, 365 and 385 nm of a UV LED) drops to about 0.6 in certain parts of the field.

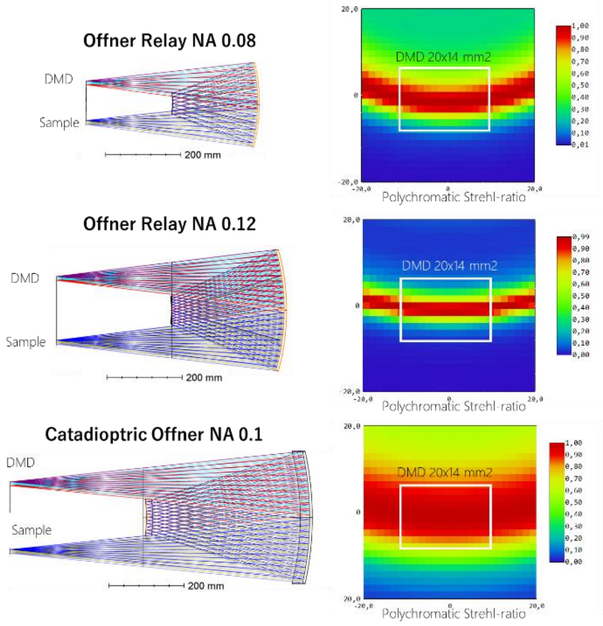

Fig. 2 *Offner relay variations and their field performance*

Increasing the numerical aperture also demands a larger working distance to allow unobstructed illumination of the DMD. It also requires larger mirrors to deal with the obscuration of the secondary mirror which in turn requires a field that is further off-axis. Both factors render the correction of higher NA successively harder. Optimizing the Offner relay with a desired numerical aperture of 0.12 (Figure 2, center) reduces the usable field even further, leaving only a thin ring-like region with diffraction limited performance. The limiting aberration is (higher order) astigmatism which the Offner relay cannot correct. Expanding the Offner setup with catadioptric

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elements (e.g. Mangin mirrors) can help to reduce the astigmatism but yields a setup with a primary mirror of almost 300 mm diameter even at reduced NA of 0.1. An example of such design is shown in Figure 2 (bottom).

While there are options to extend the Offner relay concept to a numerical aperture of 0.12 it turns out that they require a much higher level of complexity and size of the elements, rendering this a very costly approach.

3 Catadioptric Relay System

An alternative optical system has been conceived combining a single mirror with a fused silica dialyte used in a double pass arrangement as shown in Figure 3. This design is similar to a Dyson [3] design but with a long working distance and an additional lens near the mirror. Note that the mirror is reflecting on its front surface and not a Mangin mirror.

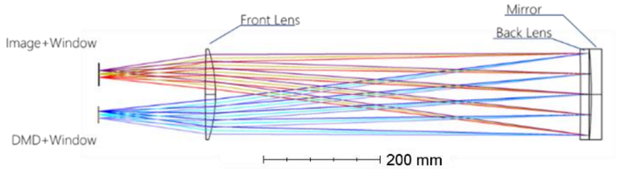

Fig. 3 *Catadioptric Relay Design*

This setup leads to interesting third order aberration properties: as the dialyte (made from the front and back lens) can be corrected for axial color (compare e.g. Schupmann lens) [4], the double pass configuration will remain color corrected for a 1:1 imaging. By virtue of the symmetry about the stop at the mirror lateral color, coma and distortion all cancel out.

For sufficiently long separations of the elements and a small departure from telecentricity, all seven third order aberrations can be corrected, using the mirror curvature to counteract field curvature and the power and bending of the silica lenses to correct spherical aberration and astigmatism. Design performance for NA 0.12 is excellent between 350 nm and 400 nm covering the spectral width of the LED as shown in Figure 4.

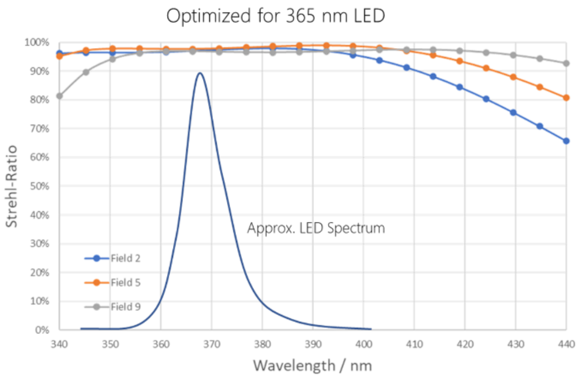

Fig. 4 *Strehl-ratio of Catadioptric Relay for different field positions of the DMD given across the spectrum*

If mirror and adjacent negative power lens are replaced by a Mangin mirror a similar correction can be achieved. However, to correct spherical aberration an aspheric surface is necessary. Such a setup yields a system with a minimum number of surfaces for this design but would require high precision manufacture of a large aspheric surface to achieve diffraction limited performance.

In addition to aberration correction and smaller mirror size, the setup has also convenient alignment properties. While spherical aberration can be compensated by the separation of the lenses the dominating alignment errors lateral color and coma can be independently corrected by tilt-alignment of the front lens and a cell holding both back lens and mirror. A test-pattern of the imaged DMD after alignment is shown in the following Figure 5 demonstrating a performance similar to the simulated diffraction image of a single micromirror (insert).

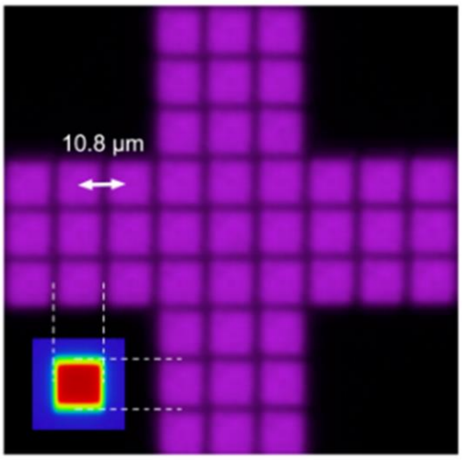

Fig. 5 *DMD pattern under UV LED lighting at sample position obtained with microscope imaging system*

Conclusion

A catadioptric relay system with just two lenses of the same material and a single mirror has been shown to be corrected for all seven third order aberrations. It is part of a maskless array synthesizer (MAS) used to create nucleic acid microarrays for research and analysis. The MAS design is available open-source [1].

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