DELIVERABLE D60.3

Microlens-fed Systems Design

WP60 Advanced Instrumentation Development

1ST Reporting Period

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PROJECT GENERAL INFORMATION

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WP 6.3

Microlens Spectrograph

Progress Report

1 Objectives

The objective of this subworkpackage is the development of a prototype of a microlens based integral field spectrograph, to be fitted on an existing spectrograph. The goal is to produce a prototype with a sufficiently large field of view to allow for the application of MOMFBD image restoration, critical spatial sampling, 3-4Å spectral range and a high spectral resolution.

2 Microlens spectrograph

The microlens spectrograph is a 2D spectrograph, that detects the light of a small spectral region at a high spectral resolution in each spatial image element in an extended field of view. To avoid overlap, each image element is reduced in size, thus creating space in which to disperse.

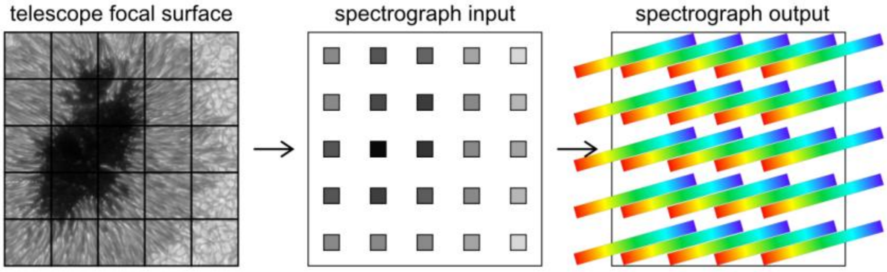

Figure 1: Microlens spectrograph principle of operation.

2.1 Instrument description

The instrument can be divided in three distinct parts, as shown in Figure 2

- Re-imager: the re-images adapts the image scale and other beam properties to that required for the microlens array to provide critically sampled image information.
- Microlens Assembly: the microlens array system is the optical component that samples the image and "shrinks" each image element to $1/n^{th}$ it's size, thus freeing up space for the spectral dimension.
- Spectrograph: the final part consists of an ordinary spectrograph with an approriate focal length and resolution

The most challenging and new optical component of the microlens spectrograph is the microlens array that reduces the image element size. We focus here on this element, as this is the first and most crucial step in the development of a prototype, whereas the spectrograph and re-imaging optics employ well-established optical principles.

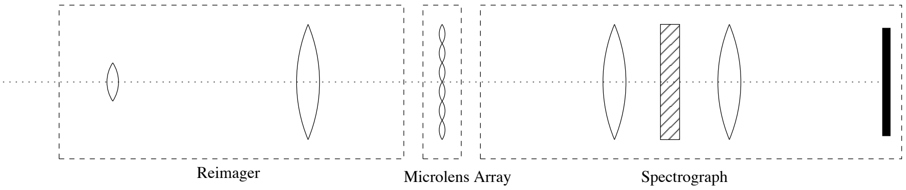

Figure 2: Basic microlens spectrograph modules.

3 Modeling

Due to the fundamental importance to the instrument and the unexplored character of this component, in the modeling of the prototype we focused mainly on the microlens assembly.

3.1 Wave propagation

The effort of developing an optical model was made more challenging by the small physical dimensions of the individual imaging elements (the microlenses). The small size of the optical elements calls for a direct propagation of the waves in the stationary case using direct integration. The Fresnel integral describes the propagation of the electric field from an extended source located in a plane at $z = 0$, to a plane located at $z = z$

$$E(x, y, z) = \frac{z}{i\lambda} \int \int E(x', y', 0) \frac{1}{r^2} e^{\frac{-i2\pi r}{\lambda}} dx' dy'$$

which under the appropriate conditions can be re-written as a convolution, which can be conveniently carried out in Fourier space. Unfortunately, these conditions are not met in the microlens system, and several optical design and simulation packages were tried (Zemax, CodeV and FRED), but none of them provided satisfactory and reliable results. As a result, a numerical code was developed in the C++ programming language, to calculate the propagation of the wavefront through an optical system of small spatial dimensions, so that the diffraction properties of the micro-optics is properly taken into account.

3.2 Modeling results

Two main results emerged from these calculations:

- The properties of the incoming beam are degraded by a factor two due to the critical sampling requirement
- A single microlens re-images the focal plane of the telescope onto the grating

The first point is intrinsic to the instrument and it does not look likely that it can be improved upon. The second point, however, has severe consequences for the performance of the instrument when used for imaging of a high-contrast object. In the presence of significant intensity gradients, the spectral response of the spectrograph can be degraded severely, resulting in a scene dependent cross-talk between the image and spectral dimensions.

The latter effect must be addressed, and calls for a second microlens array, that is used to re-image the (severely smeared out) pupil onto the grating, thus producing a constant and uniform spectral response across the field-of-view.

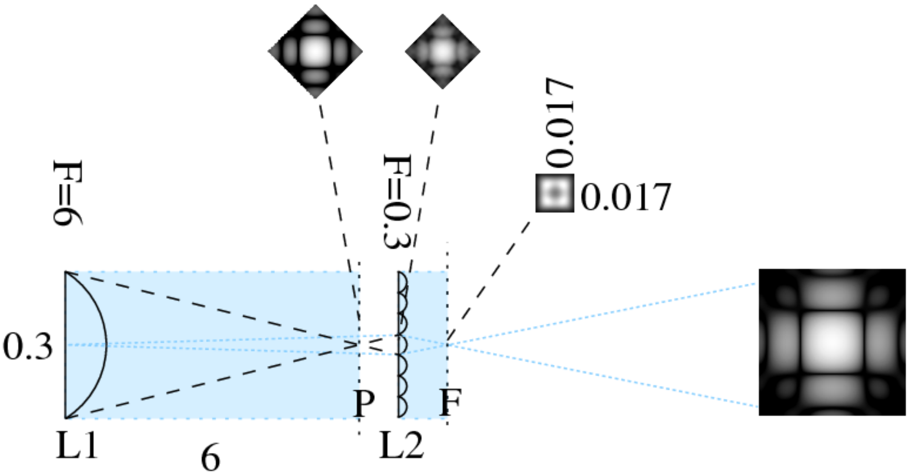

Figure 3: Dual microlens array model (not to scale). The inserted images show the intensity distribution on a logarithmic scale, except in the focal plane (indicated by F), where the intensity scale is linear.

The dual-microlens array was modeled using the numerical code and was found to image the pupil on the grating while remaining relatively (but not completely) insensitive to the intensity gradient in the focal plane. Figure 3 shows a schematic diagram of the design, with the intermediate intensity distributions in several places along the optical path.

Figure 4 indicates that the theoretical total light transmission is as high as 0.8, with a microlens pitch of $325\,\mu$m and an F-ratio of the output beam of approximately 11.

3.3 Tolerance analysis

A tolerance analysis was carried out by evaluation of the output beam properties produced by variation of the input beam properties and system configuration. The results indicated that the sensitivity to the optical quality of the optical surfaces is not very high (an RMS surface error less than $\lambda/10$ suffices), but that it is crucial that the transverse alignment of the two microlens arrays must

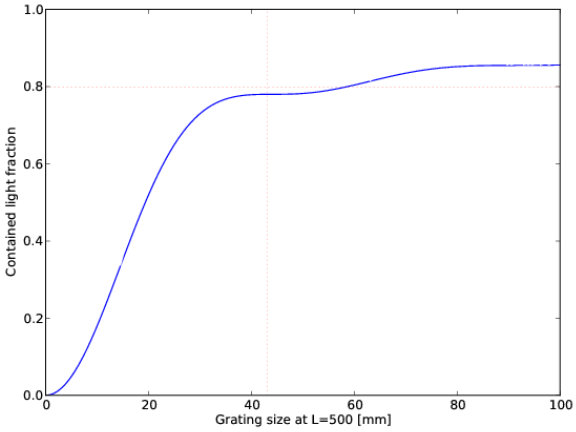

Figure 4: Curve of growth (ensquared energy).

be accomplished to approximately 1 μm. For the dimensions of the prototype, this constraint must be met at a distance of 6500 μm.

4 Fabrication

The very high alignment requirement of the design motivated the descision to produce both microlenses on a single substrate, to ensure this alignment is maintained at all times. This lead to most leading microlens manufacturers declining to make an offer

To manufacture the microlens array, we have worked on the specifications together with two leading research groups in the field of optical microstructures. The technologies most appropriate for the production of the optical surfaces were defined and some modifications to the design to accomodate those technologies were made.

5 Time line

Compared to the proposed time line, the project is currently slightly ahead of schedule. The optical modeling of the microlens assembly was more challenging than expected, but caused only a few months delay. This was mostly due to the benign response of the system to optical aberrations. The results of the modeling suggest that the output properties of the array can be designed as to make them compatible with the input properties of an existing spectrograph. Such a design was made, in negotiation with two leading research groups in the manufacturing of microstructured optical surfaces. Production of the first prototype of the microlens array and a laboratory optical setup for evaluating this prototype are currently in progress.

6 Resources

Description	requested	allocated	used to date	remaining
Man power (pm)	9.0	9.0	9.0	0.0
Equipment (ke)	61.3	61.3	0	61.3
Travel (ke)	17.0	17.0	1.2	15.8

7 Conclusion

The design of the key part of the instrument has been completed. The design was dimensioned to fit the TRIPPEL spectrograph at the Swedish Solar Telescope on La Palma, have critical spatial sampling and a nominal spectral resolution ($\sim$200000). The spectral range will be 3-4Å, sufficient to accomodate three spectral lines of interest, the field-of-view will be 128 diffraction limited pixels, approximately 7.4 arcseconds, in excess of the isoplanatic patch size of 5 arcseconds (typical) and thus sufficient for the use of image restoration.

The manufacturing tolerances of the microlens device are close to the limits of the current microstructuring capabilities, manufacturing of the prototype microlens assembly is currently underway.