DESIGN AND MANUFACTURE OF ASPHERIC LENSES FOR NOVEL HIGH EFFICIENT PHOTOVOLTAIC CONCENTRATOR MODULES

Ekkard Brinksmeier (1), Alexander Gessenharter (1), Daniel Pérez (2), José Blen (2), Pablo Benítez (2), Vicente Díaz (3), Jesús Alonso (3)

(1)Laboratory for Precision Machining LFM, University of Bremen, Germany
(2)Instituto de Energía Solar, Universidad Politécnica de Madrid, Spain
(3)ISOFOTON S.A., Málaga, Spain

Abstract

Within this project novel high efficient photovoltaic concentrator modules composed of a TIR-R (total internal reflection - refraction) lens system and small GaAs solar cells were designed and manufactured. Main objective was the development of a photovoltaic system with an efficiency of 21% and production costs not exceeding those of conventional silicon solar cells. This paper reports on the design and simulation of the concentrator, diamond machining of the ultraprecision molds for injection molding of the PMMA lenses and first functional tests of the lens system. Finally, a prototype of a photovoltaic panel consisting of 138 individual concentrator modules is presented.

Introduction

The main objective of this project is the development of a photovoltaic system with an efficiency of about 21% and production costs not exceeding those of conventional silicon solar cells [1], [2]. For this low cost and high efficient photovoltaic system a novel concentrator module was designed and manufactured basically composed of a total internal reflection (TIR) - refraction (R) lens system and a small GaAs solar cell. The lens system was designed for a 1000X light concentration (module surface: 1000 mm², solar cell surface: 1 mm²) leading to a significant reduction of solar cell costs. Moreover, the system was designed for an acceptance angle of 1.1° of the incident radiation in order to reduce the costs of the tracking system, and a uniformity of the solar cell illumination better than 2:1. The optical efficiency of the designed lens system was 82.4% (i.e. 17.6% absorption and scattering losses).

Concentrator design and simulation

The concentrator design solution consists of a primary aspheric TIR Fresnel lens and a secondary aspheric lens located between the primary lens and the solar cell. The optical path through the lens system is shown schematically in figure 1. The incident radiation is not focused on the surface of the solar cell but inside the secondary lens yielding a more uniform...
illumination of the cell. A cross-section and a 3D model of the lens system is shown in figure 2. The primary lens has a square size of 32 mm x 32 mm and a total thickness of 18 mm. It consists of eight "giant" aspheric facets with depths up to several millimeters and included angles of about 30°. The secondary lens is about 6 mm thick and exhibits an aspheric front surface and a spherical rear side.

![Fig. 2: Cross-section and 3D model of the TIR-R lens system.](image)

The optical efficiency of the TIR-R lens system was calculated for PMMA and for wavelengths between 350 nm and 1800 nm (left side of figure 3). An efficiency > 80% is achieved between 400 nm and 800 nm. This calculation includes absorption of the glass plate that covers the module as well as the absorption of the silicone used for encapsulating the GaAs solar cell. The optical efficiency decreases with an increase of the angle of incidence (right side of figure 3). The decrease is < 10% for angles of incidence < 1.1°.

![Fig. 3: Spectral dependence of the optical efficiency of the TIR-R lens system (left) and its decrease with increasing angle of incidence (right).](image)

**Mold design and manufacture of concentrator**

For injection molding of both primary and secondary lenses two complex molds were needed which were realized by diamond machining at the LFM. The design of the molds is shown in figure 4 and 5. Since diamond tools for diamond turning of very deep and narrow Fresnel grooves as required by the optical design of the TIR lens are not
available, the mold of the primary lens had to be divided into eight pieces: a square base plate with two rings for facets 1 and 6, four rings for facets 2, 3, 4 and 5, resp., a central pin exhibiting the central asphere (which is also used as inner ejector), a square plate for facet 7, and an outer square part. The outer ejector is formed by the square plate and the outer square part.

The eight pieces of the primary mold, made of aluminum AlZnMgCu1.5, were pre-machined on a Moore M18 Aspheric Generator, electroless nickel plated and diamond turned using a diamond tool with a special shank design. All cylindrical surfaces were diamond turned in order to secure a fitting tolerance of \( \pm \) 5 µm. After diamond machining, the square shape of the Fresnel lens was generated by electrical discharge machining.

The mold for the secondary lens was divided into three parts (cf. figure 5): an upper part exhibiting the aspherical cavity, a cylindrical plate containing the sprue, and a base plate with the central spherical pin. The machining sequence was similar to the primary mold.

Fig. 4: Design of primary mold.

Fig. 5: Design of secondary mold.

The geometry of the completed primary mold was measured with a Moore M18 Universal Coordinate Measuring Machine. A peak-to-valley form deviation better than 2 µm could be achieved. The figure accuracy of the molded PMMA primary lens (figure 6, left) was 60 µm to 80 µm due to inhomogeneous shrinkage. The figure accuracy of the secondary PMMA lens (figure 6, right) was well within specifications.

The geometry of the completed primary mold was measured with a Moore M18 Universal Coordinate Measuring Machine. A peak-to-valley form deviation better than 2 µm could be achieved. The figure accuracy of the molded PMMA primary lens (figure 6, left) was 60 µm to 80 µm due to inhomogeneous shrinkage. The figure accuracy of the secondary PMMA lens (figure 6, right) was well within specifications.
Prototype of photovoltaic system

Although the geometry of the giant Fresnel facets of the primary lens could not be replicated very well by injection molding, a prototype photovoltaic system consisting of 138 concentrator modules was assembled, figure 7. The GaAs solar cells were mounted on an insulated metal substrate and encapsulated by the secondary lenses. The primary lenses were positioned with respect to the secondary lenses by use of special plastic holders. Finally, a glass plate was glued on top of the primary lenses for sealing the panel.

Summary

A novel type of solar cell concentrator module, consisting of a primary TIR lens with seven giant Fresnel grooves and an aspheric secondary lens, was realized by diamond machining of electroless nickel plated aluminum molds and injection molding of PMMA lenses. The new concentrator concept could be verified. Due to the inhomogeneous shrinkage of the primary lens in the injection molding process an optical efficiency of only 55% (compared to the theoretical value of 82.4%) could be achieved. The next important step of the development will be the improvement of the injection molding process.

Acknowledgement

This work was funded by the European Community within the Fifth Framework Program under the contract number ENK5-CT2001-00548 (HAMLET).

References
