PhD thesis abstract

**New free-form optics design methods for solar concentrators and further applications**

Fabian Dürr

Integral to photovoltaics is the need to provide improved economic viability. Concentrating photovoltaic (CPV) systems use less costly optics, such as lenses or mirrors, to concentrate sunlight onto high-efficient solar cells. The ratio of optics to solar cell surface area defines the concentration ratio. A concentration ratio of 100 means that only 1% of the more expensive solar cell area is needed compared with classic non-concentrating photovoltaics.

High-efficiency multi-junction solar cells can boost the conversion efficiency of CPV modules beyond 30%, but their expense means they require a high concentration ratio exceeding a factor of 400 to be economically viable. Achieving this level of concentration normally requires dual-axis tracking of the sun's diurnal and seasonal movements. Due to their size and bulkiness, these trackers are less adequate for small- to mid-scale installations like flat rooftops. A considerable part of the installation and maintenance cost of a CPV system amounts to the external solar tracker. In contrast, photovoltaic (PV) modules with more compact and flexible single-axis trackers are already in use on flat rooftops. However, CPV systems designed for single-axis trackers are limited to concentration ratios not high enough to make economic use of multi-junction solar cells.

In this work, we propose a fundamentally new approach to CPV which integrates part of the external solar tracking functionality into the CPV module. The system consists of two laterally moving lens arrays, combining the concentration and steering of the incident sunlight. To unleash the full potential of the considered system, a free-form optics design is absolutely essential. Given the very large number of parameters needed to describe such surfaces, the design and optimization of free-form optics is far from being trivial. The final solution obtained by global optimization algorithms is highly dependent on the initial design. It cannot be guaranteed that optimization will find the global minimum.

In contrast, direct free-form design methods developed in recent years allow a direct calculation of the optical surfaces without iterations. One particular method, the Simultaneous Multiple Surfaces (SMS) design method, has served as a starting point. It has proven to be very effective in designing optics for concentrating photovoltaics and found its way into various successful applications. As moveable optics has not been foreseen in any direct design method so far, we developed an extended SMS design method for laterally moving lenses.

Even though this approach gave already promising results, the design method raised new questions about how to select its initial values. To address this problem, we developed a new analytic optics design method capable of calculating the surfaces of the moveable free-form lenses. Performance simulations showed that the obtained analytic free-form lens design outperformed all preceding optical designs. Based on this free-form optics design, it is possible for the first time to use more compact and flexible single-axis trackers without being forced to abandon high-efficiency multi-junction solar cells; key to open small to mid-scale installation markets for CPV.

Furthermore, we have shown that this new free-form optics design method has potential for other application areas. For imaging systems with high aspect ratio, ray tracing simulations for calculated free-form lenses demonstrated superior imaging performance when compared to conventional rotational symmetric systems.