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硕 士 学 位 论 文

光栅型太阳能聚光器的设计及制作

The Design and Production of Grating-based Solar
Concentrator

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摘要

聚光光伏技术可以提高太阳能电池的转换效率和降低光伏系统的发电成本，在太阳能开发和利用中占有重要的地位，对其进行的研究和探索也是光伏领域中的一个热门课题。荧光太阳能聚光器（Luminescent Solar Concentrator, LSC）作为一种新的聚光形式虽然诞生较晚，但因其相对于传统聚光方式具有独特的优势，正在吸引着越来越多的科技工作者投入到这一领域的研究中。

自从 LSC 诞生到现在的三十多年来，在荧光材料、基底材质和器件结构等方面都取得了一定的进展。目前对 LSC 的研究还主要局限于荧光染料的研究上面，对器件聚光模型的改进则鲜有进一步的报道。针对这一现状，本论文以 LSC 聚光模型为基础，将光栅衍射应用到聚光领域中，制作出了光栅型太阳能聚光器，并对其聚光性能进行了仿真研究和实验测量。

本论文的研究内容主要包括以下几个方面：

1. 首先，论文在原理方面对光栅型太阳能聚光器建立了物理模型，对其工作方式进行了介绍，并推导出了接收角，聚光比等性能参数与器件结构参数的关系，从而对光栅型太阳能聚光器的聚光原理和模型作了说明。

2. 其次，利用光栅计算分析软件 GSolver 和光迹追踪模拟仿真软件 Tracepro 对所建立的模型进行仿真实验，这主要包括两部分内容：一是计算分析光栅的衍射效率（包括一级透射衍射效率和零级反射衍射效率）与光栅的槽深、占空比等参数的关系，据此选择合适的光栅参数生成光栅表面数据，然后在 Tracepro 中建模并进行仿真实验。对正弦和矩形两种槽型的光栅聚光器，仿真实验结果分别得到了 4.4%和 9.7%的集光效率，且均表现出了较大的接收角度；结果还表明，器件出射面的光通量分布具有良好的均匀度，若将光栅聚光器设计成多层叠加结构，可以有效地拓宽器件的工作谱段范围和提高输出面的光辐射通量。

3. 最后，为了验证软件联合模拟工作的可靠性，论文中还实际制作了一个光栅聚光器，测量了其实际工作性能，并与以此参数建模的仿真实验结果数据进行了对比，结果表明软件的联合模拟工作是准确和可靠的。

关键词： 光伏发电；荧光太阳能聚光器；光栅型聚光器；GSolver；Tracepro

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Abstract

As the concentrating photovoltaic (CPV) technology can improve the efficiency of the solar cells and reduce the cost of the PV systems, it is quite important for the development and exploitation of solar energy and also one of the hot topics in the field of photovoltaic. Although Luminescent Solar Concentrator (LSC) emerges later as a new form of CPV, it is attracting more and more attention of scientists for its unique advantages over the traditional concentrator.

During more than 30 years since the birth of LSC, great achievements have been made in research on fluorescent materials, base materials, device structure, etc. However, the present studies on LSC mainly focus on fluorescent dyes and those on concentrating model are quite rare, which still need further exploration. Consequently, on the basis of LSC, this thesis applies the grating to CPV and produces a grating-based concentrator, the performance of which is also simulated and tested.

Research of this thesis is mainly composed of three parts:

1) A physical model of CPV is built theoretically. By introducing how it operates and inferring the relationship between performance parameters and structure parameters of the device, the concentrating principle and model are elaborated.

2) Simulation experiments are made about the model by making use of the diffraction grating analysis program GSolver and ray tracing program Tracepro, which mainly includes two parts: according to the computation and analysis of the relationship between diffraction efficiency (both of the first order diffraction efficiency of transmission and diffraction efficiency of reflection) and the parameters of the grating, the appropriate grating parameters are selected to generate grating surface data; then the model is built and simulation experiment is also carried out in Tracepro. The result shows that sinusoidal grating and rectangular grating concentrators both exhibit a wide angle of acceptance and good energy uniformity on the exit plane, with the collection efficiency of 4.4% and 9.7% respectively. If they are designed into multi-layer structures, the spectral range can be extended efficiently

and radiation flux of the exit plane could also be improved.

3) To verify the reliability of these two programs' cooperation, a grating-based concentrator is made and its performance is also tested. The data obtained in this way is compared with those got from the simulation experiment, which proves that these two programs' cooperation is accurate and reliable.

Keywords: Photovoltaic; Luminescent Solar Concentrator; grating-based concentrator ; GSolver; Tracepro

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