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A novel capacitive pressure sensor and interface circuitry

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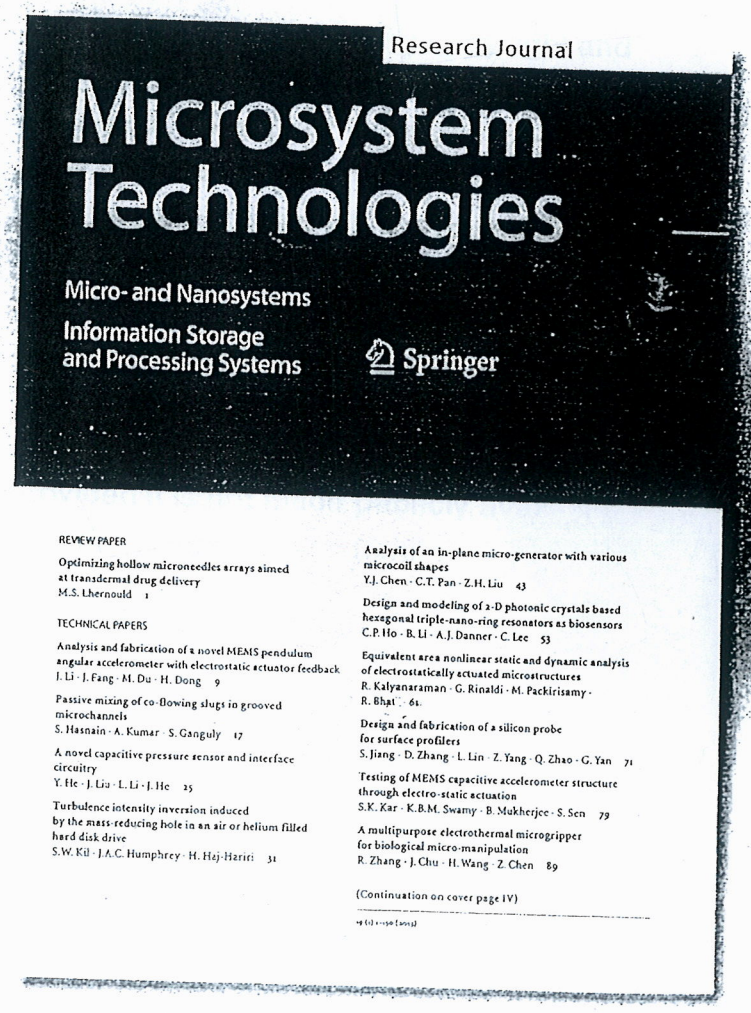

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TECHNICAL PAPER

A novel capacitive pressure sensor and interface circuitry

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Abstract A novel capacitive pressure sensor with the island-notch structure is introduced. Its theory model is established based on the structure theory of the plate capacitive pressure sensor. The relationships between the external pressure and capacitance of the capacitive pressure sensor with the island-notch structure are studied by using the method of the finite element analysis (FEA). The results show that the linearity of the capacitive pressure sensor with island-notch structure reached up 0.9941 in the linear measurement zone, the sensitivity reached up 0.0019 pF/kPa, and the measurement range of the capacitive pressure sensor is enlarged. Thus, the contradictory among measure sensitivity, linearity and measure range is effectively relieved in the capacitive pressure sensors with island-notch. In addition, the interface circuitry of the charge transfer is designed, and the performance of the interface circuitry is analyzed.

1 Introduction

Because the capacitive pressure sensors have the advantages of the direct current stabilization, excursion little and low power consumption, the capacitive pressure sensors are widely used in the pressure measurement, the angle velocity measurement and the acceleration measurement, etc. In order to improve the sensitivity and the linearity of the capacitive pressure sensors, the different structure of the capacitive pressure sensor is designed by using MEMS technology (Li and Mehregany 2008; Shan et al. 2008; Lv et al. 2008; Peng et al. 2009; Munnangi et al. 2008). Moreover, the influence of different plate structure to characteristics of the capacitive pressure sensors is further studied in the previous works. For example, the linearity of the capacitive pressure sensor could be improved by using the island film structure instead of the flat film structure (Shan et al. 2008). But this method reduces sensitivity of the capacitive pressure sensor. The capacitive pressure sensor with the double-notch is designed (Lv et al. 2008). The measure range of the capacitive pressure sensor with the double-notch is enlarged. But the linearity of the capacitive pressure sensor with the double-notch is worse. In addition, proved that the capacitive pressure sensor with the circular film has better the sensitivity and the linearity comparing with the one with square film is proved by using the deformation characteristics of the circular film and square film (Pedersen et al. 2009). However, the contradictory among the measurement range, measurement sensitivity and linearity has existed in the previous capacitive pressure sensor. In the paper, according to the advantages of island film structure and notch structure, the capacitive pressure sensor with island-notch structure is designed, and the characteristics are analyzed by using the method of the finite element analysis (FEA). The results show that the sensitivity and linearity of the capacitive pressure sensor can be improved, and the measurement range of the capacitive pressure sensor is enlarged by using island-notch structure.

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2 Characteristic of capacitive pressure sensor with island film and circular notch

The nice linearity of the capacitive pressure sensor with the island film is proved (Peng et al. 2009). The profile

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Theoretical and experimental study on the application of diffuse-reflection concentrators in PV/T solar system

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SUMMARY

In order to improve the practicability of PV/T solar system, we proposed the theory and method on the application of diffuse-reflection concentrator in the PV/T solar system and analyzed the concentration characteristics of this proposed application. In addition, we designed experimental prototype of PV/T solar system and conducted test and analysis of the thermal and electrical characteristics of the PV/T solar system with or without a concentrator, respectively. The results showed that for the PV/T solar system with diffuse-reflection concentrator, the amount of incident irradiance was increased by an average of 26% during test period, and the 200-L water in the system was heated to 58 °C, which was 12 °C higher than that of PV/T solar system without diffuse-reflection concentrator; moreover, the max output power was increased by 11%. Therefore, it is a feasible way to improve the practicability of PT/V solar system by integrating a diffuse-reflection concentrator. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS

PV/T solar system; diffuse-reflection concentrator; photothermal properties; photoelectric properties; practicability

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1. INTRODUCTION

In 1978, Kern and Russell [1] proposed the concept of PV/T solar system for the first time. After that, the theory of PV/T solar system was further analyzed, for example, Florschuetz *et al.* [2] introduced the design model of PV/T solar system and theoretically calculated that the use ratio of solar energy in the PV/T solar system was about 60–80%. Vorobiev *et al.* [3] introduced the characteristic of PV/T solar system with glass insulation cover. Rosell *et al.* [4] introduced the prototype of PV/T solar system using Fresnel concentrator system and two-axis solar-tracking system. Swapnil Dubey *et al.* [5] introduced the PV/T solar system made of flat plate collectors in series connection and analyzed the design model. Liu *et al.* [6] discussed the influences of fin height, spacing of fins, and internal diameter of the pipeline upon the thermal property of natural circulation PV/T water-heating system with flat-box. Wei *et al.* [7] introduced that compared with the simplex photovoltaic power generation system, the energy usage ratio per unit area of PV/T solar system was higher by 200–300%. Charalambous *et al.* [8] conducted analysis on the optimization technique of collector structure of PV/T solar system and proposed a thin plate collector structure. The weight of the proposed structure equals to that of traditional plate collector structure after being reduced by 40.5% [8]. In addition, Ji *et al.* [9] designed PV/T solar system and tested photoelectric and photothermal properties of the system under natural circulation mode in Hefei region. The results showed that the comprehensive efficiency of the system was greatly increased as compared with that of the simplex PV or thermal system [9]. Moreover, Moradi *et al.* [10,11] analyzed the research progress of PV/T solar system. Recently, Reddy *et al.* [12] developed the PV/T collector and Phase Change Material (PCM) unit in order to be easily implemented into a practical building management system. Fiorentini *et al.* [13] emphasize on thermal management and efficiency using single-phase flow-based cooling techniques.

It can be seen from the aforementioned reported researches that the PV/T solar system is of higher efficiency in theory and the optimized designing technique for such system was focused. However, there have been some problems including the unbalance between the collector operating temperature and conversion efficiency, and the poor practicability of PV/T solar system. As a result, based on the structure theory of PV/T solar system, we designed diffuse-reflection collector and researched the theory and

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Research on the influence of PV cell to thermal characteristics of photovoltaic/thermal solar system

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SUMMARY

In the paper, we analyzed internal thermal transmission characteristics of water-heating photovoltaic/thermal (PV/T) solar collector covered by photovoltaic (PV) cell, established photothermal conversion model of PV/T solar system, and analyzed the influence of PV cell coverage to photothermal characteristics of PV/T solar system. Results show that the thermal efficiency of PV/T solar system by optimizing PV cells coverage can reach 68%. In addition, by designing four water-heating PV/T solar system prototypes with PV cell coverage of 0.4, 0.56, 0.7, and 0.82, respectively, we conducted experimental researches for the four prototypes and found that the four prototypes can achieve thermal efficiencies of 58%, 51%, 64%, and 67%, respectively, in heating 250 L of water to 50°C. The experiment results are consistent with theoretical analysis results, indicating that it is feasible to improve thermal characteristics of PV/T solar system by optimizing PV cell coverage. Copyright © 2017 John Wiley & Sons, Ltd.

KEY WORDS

PV/T solar system; PV cell; thermal characteristics; practicability

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1. INTRODUCTION

In 1978, Kern and Russell proposed the concept of photovoltaic/thermal (PV/T) solar system [1], which is a dual energy system that can output both electricity and heat. PV/T solar system is regarded as the most effective method of utilizing solar energy, with total efficiency up to 70% [2,3]. The methods of thermal management in PV/T systems have been investigated, and PV/T solar system in different configurations has been successfully developed, which can be divided into air-heating PV/T solar system and water-heating PV/T solar system according to the difference of heat transfer medium [4–10]. For example, Dubey *et al.* conducted experimental research on air-heating PV/T solar systems with different photovoltaic (PV) cell configurations in New Delhi [11]; higher electrical efficiency and outlet temperature were achieved with the glass-to-glass PV module type with duct. Tonui and Tripanagnostopoulos made numerical simulation analysis on air-heating PV/T solar system [12]. Results showed that at a channel depth of 0.15 m, the temperature of the PV cell module is reduced by 3°C and the output electrical efficiency of the PV cell modules increased by 1%. Ibrahim *et al.* designed different configurations of water-heating PV/T collector, and its performance was studied. Under water flow rate of 0.01 kg/s, spiral flow design proved to be the best design with the highest thermal and PV cell efficiencies of 50.12% and 11.98%, respectively, and output temperature of 31°C [13]. Ji *et al.* developed a set of water-heating PV/T integrated solar system through pressing solar cell module on aluminum alloy water heater collector with flat box. This integrated solar system can achieve daily thermal efficiency of 40% and daily electric efficiency of about 9.15% in sunny or cloudy day [14]. In addition, Pei *et al.* successfully designed heat pipe PV/T solar system by pasting heat pipe on aluminum plate and utilizing gaps between PV cells, of which average electric efficiency was measured as 10.2% and average thermal efficiency as 45.7% [15]. Ma *et al.* studied PV/ST/phase change materials system, which can increase electricity output by 9% and increase average temperature of water by 20°C [16]. Bojanampati *et al.* experimentally investigated both air and water forced cooling methods for PV cell. The outcome of their work shows that an air cooling system reduced temperature by 11.4°C whereas the chilled water cooling decreases it by 32.9°C [17].

However, the application of water-heating PV/T solar system has not been promoted for its poor practicability. The main reasons are due to the high cost of the system.

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RESEARCH ARTICLE

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Study on design and thermal characteristics of vacuum tube solar collector intubated with heat storage tube

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Summary

In this work, a heat storage vacuum tube solar collector intubated with heat storage tube is designed, which consists of solar vacuum tube, phase change material insert tube, and heat holding cover. The internal energy conversion, transmission, and storage theory are established based on the structure of the heat storage vacuum tube. The parallel and series-parallel solar air collector system prototype consisting of nine heat storage solar vacuum tube solar collectors is designed and tested. The test results showed that the daily average conversion efficiency of the parallel and series-parallel prototype reached 56.9% and 48.46%, respectively. Compared with nonheat storage prototype, the heat storage parallel and series-parallel prototype had higher conversion efficiency by, respectively, 10.9% and 7.8%, longer effective heating time, and better heating stability and practicability. At the same time, the heat storage solar collector has compact structure, which is convenient to use.

KEYWORDS
heat storage, solar vacuum tube, heat storage insert tube, phase change material (PCM)

1 | INTRODUCTION

The output heat of solar air collector is unstable due to the instability, day-night alternation, and seasonality of solar radiation, which limits the application of solar collectors in material drying and heating systems to a certain extent.[1-3] In order to improve stability of solar collector system, solar and electrothermal hybrid heating systems are designed, but solar energy is still noneffectively applied in these systems.[4] Phase change material (PCM) heat storage technology has been widely used and studied in solar energy collector system. Bai et al designed a novel solar heating system with heat pipe type heat storage vacuum tube and carried out experiments to investigate its working thermal characteristics. The results showed that the useful efficiency could reach 50.5%.[5] Wang et al designed a solar air collector system integrated with phase change heat storage material and flat-panel microheat pipe array. When the air flow rate was 60 $m^3\ h^{-1}$, the output air temperature of the system can be maintained stable.[6] Arkar et al designed a solar air heating system with direct-through vacuum heat storage tube. The research showed that 54% to 67% of the heat generated by solar energy system during the day could be used to heat buildings at night.[7] Plytaria et al added PCM heat storage layer under the floor of the room in solar-assisted heating system, which reduced energy consumption by 65%.[8] Agarwal et al designed a tubular paraffin phase change heat storage device and analyzed the influence of heat storage device on solar drying system characteristics.[9] Khadraoui et al conducted an experimental study on the influence of PCM heat storage units on solar air collectors, providing an experimental basis for evaluating importance of PCM heat storage units.[10] Enibe designed a passive solar air heating system integrated with a flat-plate solar collector and a PCM heat storage unit.[11] Jing et al designed and processed a flat-plate solar collector integrated with phase change heat

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部分覆盖光伏/光热太阳能系统优化设计与实验

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摘 要：介绍一种部分覆盖太阳电池的光伏/光热(PV/T)太阳能系统。在PV/T系统中，设计使用两个面积为2 m²、太阳电池面积为0.6 m²的平板PV/T集热器，并对PV/T系统设计的理论和能量转换特性进行研究分析。在楚雄市，所设计的PV/T太阳能系统样机分别在晴天(2013年5月28日)和多云阴天(2013年6月23日)进行特性测试。结果表明，晴天，PV/T系统的热水温度可达66.5 ℃，一日内(08:05~18:05)系统输出平均电功率为34.0 W；多云阴天，PV/T系统的热水温度可达57.0 ℃，一日内(09:10~18:10)系统输出平均电功率为33.1 W。PV/T系统输出日热效率为45.5%，可满足农村普通家庭热水和照明电能需要，具有较高的实用性。

关键词：太阳能；PV/T系统；热效率；电效率

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0 引 言

1978年，Kern和Russell提出了PV/T太阳能系统的概念[1]。PV/T太阳能系统能同时输出电能和热能，是一个双生能系统。其后，PV/T太阳能系统在理论上得到大量研究。例如，Florschuetz[2]和Radziemska[3]介绍了PV/T太阳能系统的设计理论，太阳能利用率可达60%~80%。文献[4]分析了带玻璃罩PV/T太阳能系统特性，并对玻璃罩对系统特性影响进行了研究。文献[5]设计了使用菲涅尔聚光技术和两轴太阳跟踪系统的PV/T太阳能系统，实验结果表明其热性能可达到60%。Swapnil等[6]介绍了多个平板集热器串联的PV/T太阳能系统设计理论。另外，文献[7]介绍了空气型PV/T系统，并在天津地区对系统进行了测试。在自然通风冷却条件下，系统电效率为4.61%，热效率为26.1%。

PV/T太阳能系统在理论上具有较高的能量转换效率。但由于受工艺、太阳电池工作温度等限制，存在系统输出温度低、实用性较差等问题。尤其是水加热型PV/T系统，目前，无成熟的产品被使用。本文在上述研究的基础上，设计部分覆盖太阳电池的水加热型PV/T太阳能系统，通过解决光电转换效率与输出热水温度(热效率)之间的平衡问题，提高PV/T系统实用性。并在两种天气条件下对PV/T系统的光伏、光热特性进行实验测试及分析。

1 PV/T太阳能系统设计理论

1.1 太阳电池温度-太阳辐照度特性

太阳电池在光电转换过程中，仅有5%~15%的入射太阳能转换为电能，其余能量部分被反射，部分被吸收转换为热，使太阳电池温度升高。太阳电池温度随入射太阳辐照度的增加而升高，其变化关系如式(1)所示[3]。

$$T=t_a+(NOCT-20)\frac{E}{800} \tag{1}$$

式中，T——太阳电池温度，℃；t_a——环境温度，℃；E——太阳辐照度，W/m²；$NOCT$——标称工作温度[3](太阳辐照度为800 W/m²，环境温度为20 ℃，风速为1 m/s条件下，计算太阳电池的工作温度时，采用塑料基板太阳电池的标称工作温度约为47℃)。

1.2 太阳电池转换效率-温度变化特性

太阳电池的转换效率指受光单体太阳电池最大输出功率与辐射到该电池受光面积上全部光功率P_{in}之比，如式(2)所示。

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基于模型分析的光伏/热(PV/T)太阳能系统设计方法及应用研究

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摘 要：根据聚光PV/T热水太阳能系统的结构特点，分析聚光PV/T热水太阳能系统的设计参数，结合聚光PV/T热水太阳能系统的能量转换、存储和传输特性及用户对系统输出电能、热能的需求，建立聚光PV/T热水太阳能系统光电、热能量转换效率、热水温度及输出电能的设计优化理论模型。并利用设计模型分析不同设计参数对系统输出热、电能量的影响，有效简化聚光PV/T热水太阳能系统的优化设计过程。另外，设计聚光PV/T热水太阳能系统样机，并对其特性进行实验分析。结果表明，系统输出能满足农村家庭对照明电能、热水的基本需要，具有较好的实用性。

关键词：太阳能；光伏/热；太阳能系统；设计模型；实用性

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0 引 言

在独立光伏发电系统中，太阳能量仅有5%~15%被利用，大量入射太阳电池的太阳能转化为热能，导致太阳电池温度升高，降低其转换效率。为了提高太阳能能量的利用效率，1978年，Kern Jr.等[1]提出了光伏/热太阳能系统的设计概念。随之，PV/T系统的理论及实验得到较为广泛的研究，例如：Bergene等[2]对水加热光电/热太阳能系统做了理论分析，Vorobiev等[3]对带玻璃罩的光电/热太阳能系统特性进行了研究。Swapnil等[4]研究了多个平板集热器串联的光电/热太阳能系统，并对其进行了分析。魏晨光等[5]介绍PV/T系统相对于单一的光伏发电系统，单位面积的能量利用率会有200%~300%的提升。Sandnes等[6]在耐热塑料扁盒上粘贴单晶硅电池，制成PV/T集热器。季 杰等[7,8]把太阳电池组件层压在热水器的扁盒式铝合金集热板上，构成一套光伏光热(PV/T)一体化系统，并在合肥地区进行了自然循环模式下的光电光热性能测试。实验结果表明，在晴朗或多云的天气条件下实验系统日平均热效率可达40%，日平均发电效率约9.15%。赵 军等[9]介绍了空气型PV/T系统，并在天津地区太阳辐射条件下，对系统特性进行了测试。

总之，PV/T太阳能系统具有较高的理论效率，但是，PV/T热水太阳能系统的实用性较差，还没有成熟的产品被推广使用[10,11]。究其原因，主要在于PV/T热水太阳能系统存在工作温度与效率之间的矛盾，且优化设计过程和加工工艺较为复杂。本文根据低聚光PV/T热水太阳能系统的结构，分析不同设计参数间的关系，建立聚光PV/T热水太阳能系统输出电能、热能、水温的设计模型，并根据用户对电能、热能及热水温度等的需求，分析不同设计参数对系统特性的影响，简化系统优化设计的过程，为提高系统的实用性奠定理论基础和提供一种新的优化设计方法。

1 聚光PV/T热水太阳能系统的基本结构及主要参数

聚光PV/T热水太阳能系统结构模型如图1所示。

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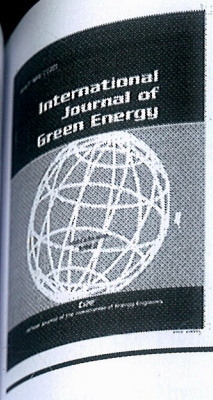

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PCM thermal conductivity effect on mechanism of PV/PCM thermal control characteristics

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PCM thermal conductivity effect on mechanism of PV/PCM thermal control characteristics

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ABSTRACT

According to the structure of photovoltaic/phase change material (PV/PCM), the mechanism of internal heat transfer, transmission, storage, and temperature control is analyzed, and a two-dimensional finite element analysis model of PV/PCM structure is established. This study is carried out on the effect of PCM thermal conductivity on internal temperature distribution characteristics of PV/PCM and temperature control characteristics of solar cells. The results show that the increase in thermal conductivity of PCM can prolong the temperature control time of solar cell in PV/PCM system, for example, when the thermal conductivity is increased from 0.2 W/(m·K) to1.5 W/(m·K) under a thickness of 4 cm, the duration when PV/PCM solar cell temperature is controlled below 40°C and extended from 52 min to 184 min. In addition, PV/PCM experimental prototypes are designed with the LA-SA-EG composite PCM peak melting point of 46°C and thermal conductivity of 0.8 W/(m·K) and 1.1 W/(m·K), respectively. The results indicate that compared with PCM-free solar cells, the maximum temperature of PV/PCM prototype solar cells with thermal conductivity of 0.8 W/(m·K) and 1.1 W/(m·K) is reduced by 10.8°C and 4.6°C, respectively, with average output power increased by 4.1% and 2.2%, respectively, under simulated light sources. Under natural light conditions, the average output power is increased by 6.9% and 4.3%, respectively. The results provide theoretical and experimental basis for the optimization of PV/PCM design by changing the thermal conductivity of PCM.

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KEYWORDS
Phase change material; PV/PCM (photovoltaic/phase change material); solar cells; temperature control; thermal conductivity

1. Introduction

Development of the world economy is accompanied by countries' increasingly prominent dependence on energy. However, traditional petrochemical energy has diminishing storage and brings ambient atmosphere pollution in use. Therefore, the development and utilization of renewable clean energy have become a national strategy of countries around the world. Solar photovoltaic (PV) power generation represents one of the most extensive applications. In China, at the end of 2019, installed capacity of solar PV power generation has reached 210 GW. Nevertheless, in solar PV power generation, solar cells can only convert 5–17% of incident solar energy into thermal energy. More than 80% of solar energy is converted into thermal energy, causing the increased temperature of solar cells (Al-Waeli et al. 2017a). When the temperature of crystalline silicon solar cells exceeds 25°C, its conversion efficiency will reduce by 0.4–0.65% for every increase of 1°C (Hasan et al. 2010; Radziemska 2003). Hence, increased temperature of solar cells is one of the main factors leading to decreased output power. Controlling solar cell temperature has already become a new research area (Browne, Norton, and McCormack 2015; Huang et al. 2011; Ma, Yang, and Zhang 2015). Where phase change materials (PCM) maintain the same temperature while absorbing heat during the phase change process. Such characteristic attracts wide research and application interest in solar cell thermal control. For example, using finite element analysis, (2011, Huang et al. (2006a), and Huang et al. (2006b) analyzed the thermal and electrical characteristics of a solar thermal control system of PV/PCM. The study shows that building a solar cell thermal control system using PCM can increase the output power of PV systems by 6%. Smith, Forster, and Crook (2014) established a 1D PV/PCM model and studied the photoelectric and thermal characteristics of PV/PCM at different temperatures. Tan (2013) research shows that PCM application in concentrator solar cells can increase the output conversion efficiency of solar cells by 5% and reduce the solar cell temperature by 15°C. Mousavi Baygi and Sadrameli (2018) designed a PV/PCM system using polyethylene glycol as PCM. Experiments show that compared with solar cells without PCM thermal control, the temperature is reduced by 15°C and the conversion efficiency is increased by 8%. Jungwoo, Taeyeon, and Seung-Bok (2014) designed a PV/PCM experimental system. Experiments show that the solar cell temperature in the PV/PCM system is 5°C lower compared to a single solar cell, and the conversion efficiency is increased by about 3.1%. Hasan et al. (2014) carried out experimental research on the designed PV/PCM system under the irradiance of 1000 W/m^2. The results showed that the solar cell temperature decreased maximally by 18°C within 30 min and decreased by 10°C within 5 hr. In addition, Malvi, Dixon-Hardy, and Crook (2011) added metal fins to the PCM thermal control unit to improve PV/PCM performance. The results show that a 10% increase in PCM thermal conductivity can increase PV power generation by 3%. Nada, El-Nagar, and Hussein (2018) conducted a comparative test on solar cell thermal control systems

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Modeling of Photoelectric Micro-Power Supply for Wireless Sensor Nodes

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Abstract For the wireless sensor node integrated with photoelectric micro-power supply, the photoelectric micro-power supply (PMPS) determines their life time, stability and adaptability to the local environment. The design of PMPS involves the study related to incident light power, photoelectric conversion efficiency of solar cells, characterization of storage devices, energy management and operation state control of sensor nodes, etc. The design process of PMPS is complicated. In this study, in order to simplify the design process of the PMPS and optimize it, we analyze all of the power parameters for the PMPS for sensor nodes. According to the energy transmission modes of PMPS for sensor nodes, the design model of PMPS is established. The rationality of PMPS is verified by experiments and simulations based on wireless sensor node (Ginze3).

Keywords Solar cells · Micro-power supply · Modeling · Sensor nodes

1 Introduction

Sensor nodes integrated with photoelectric micro-power supply (PMPS) is widely researched in recent years. Prometheus [1] and Heliomote [2] are the earliest sensor nodes using PMPS. The sensor nodes using photoelectric and thermoelectric hybrid micro-power supply is presented in our reports [3, 4]. For sensor nodes integrated with PMPS, however, the schemes of energy conversion, energy storage and energy management determine the lifetime of sensor nodes and its capability to the local environment. The design process of PMPS is related to many factors: solar irradiance, photoelectric conversion efficiency of solar cells, the power consumption of sensor nodes, etc. [5, 6]. In order to simplify the process of the designing PMPS and optimizing PMPS, it is necessary to establish the design model of PMPS. In this paper, first, all power parameters of different subsystem in PMPS are introduced and their characteristics are analyzed. Second, according to structure of PMPS, the modes of energy transmission are introduced and the characteristics of energy transmission are studied. Third, the designing model of PMPS is established based on the modes of energy transmission. Four, results of simulation combined with Ginze3 for the designing model and experiment results of sensor node integrated with PMPS are introduced.

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2 Power Parameters Analysis of PMPS

Sensor nodes integrated with PMPS are comprised of four subsystems: energy conversion subsystems, energy storage subsystems, energy management subsystems, and sensor nodes. The structure diagram of PMPS is shown in Fig. 1.

In Fig. 1, A and B show different modes of energy transmission in PMPS respectively. In order to establish the design model of the PMPS and to optimize the PMPS, it is necessary to analyze all power parameters for different subsystems of PMPS and to analyze different modes of energy transmission.

2.1 Power Parameters of Energy Conversion Subsystem

In the energy conversion subsystem, solar cells convert light energy into electrical energy. The output efficiency of

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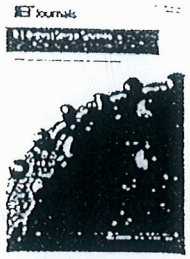

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Design of solar photovoltaic micro-power supply for application of wireless sensor nodes in complex illumination environments

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Abstract: The advantages of the wireless sensor nodes, integrated with the solar photovoltaic (PV) micro-power supply, have been proved, and some design technologies of the solar PV micro-power supply have been proposed in the previous report. However, using the wireless sensor nodes integrated with the solar PV micro-power supply is limited in complex illumination conditions because of the low energy conversion efficiency of the solar PV micro-power supply. To enlarge application environment of the wireless sensor nodes integrated with the solar PV micro-power supply, it is crucial to enhance the energy conversion efficiency of the solar PV micro-power supply in complex illumination conditions. In the study, a novel solar PV micro-power supply using the optimal voltage control technique and the solar cells array in series–parallel has been designed. Moreover, the wireless sensor node integrated with the solar PV micro-power supply has been achieved. In different illumination environments, the performances of the solar PV micro-power supply have been tested. According to test results, the solar PV micro-power supply can keep high output conversion efficiency and the output stability in complex illumination conditions.

1 Introduction

In order to prolong the working lifetime and realise self-power of wireless sensor nodes, the wireless sensor nodes integrated with solar photovoltaic (PV) micro-power supply have been widely studied in recent years. The sensor nodes integrated with solar PV micro-power supply have been achieved, such as Prometheus [1], Heliomote [2]. In the solar PV micro-power supply, the solar cells are conventionally connected in series to obtain the desired voltage, and the output of solar cells is directly stored in energy storage devices to simplify the energy management system. Thus the efficiency of these systems is lower, and the reasonable charge requirement of the energy storage devices cannot be met. In order to improve the output efficiency of the solar cells array, the MPPT technique is used in the design of the solar PV micro-power supply [3–7]. However, the effect of MPPT is not significant in solar cells array with low output voltage and low power [3]. To improve the output efficiency of the solar cells array with low output voltage and low power, the optimal voltage control technique is proposed [8, 9], and the design model of the solar PV micro-power supply is established [10]. In addition, the photovoltaic thermoelectric hybrid micro-power supply is designed as the power supply of the wireless sensor nodes. The thermoelectric generator converts the thermal energy from the rear surface of solar cells into the electrical energy. The utilisation efficiency of environmental energy is enhanced by using photovoltaic thermoelectric hybrid energy harvest [11, 12]. However, in the micro-power supply using the environment energy, the effect of the different light conditions to the energy conversion efficiency is larger. Moreover, so far researchers seldom consider the techniques of solar PV micro-power supply for improving the energy conversion efficiency in partial shading or complex illumination environments. To solve this problem, we design a novel solar PV micro-power supply by using the optimal voltage controller and the solar cells array in series–parallel.

The body of this paper includes three parts. In Section 2, we have introduced the characteristics of the solar cells array in series and the solar cells array in series–parallel, and designed a prototype of solar PV micro-power supply by using the optimal voltage controller and the solar cells array in series–parallel. In Section 3, we have carried out the experimental test for the prototype of solar PV micro-power supply in different illumination environments, and analysed the experimental results. The conclusions have been presented in Section 4.

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Research of Solar Photoelectric Micro-power Supply on Chip

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Keywords : Micro-power Supply Solar Cells Wireless Sensor On-chip

Abstract. In order to reduce volume of MEMS wireless sensor with solar photoelectric micro-power supply, the integration scheme of solar photoelectric micro-power supply on chip is proposed in the paper. The scheme is consisted of seven main process steps, and has higher process compatibility. The characteristics of the integrated devices of the solar photoelectric micro-power supply are analyzed by using the semiconductor theory. The results show the device characteristics meet the requirement of the solar photoelectric micro-power supply. Moreover, the technology improving conversion efficiency of solar cells on chip is proposed by use of the back surfaces field (BSF). The conversion efficiency of solar cells reached 13.4%.

Introduction

With development of MEMS and microelectronics technology, the power consumption and volume of MEMS wireless sensor are decreased significantly. Thus, the micro-power supply integrated MEMS wireless sensor is attracting more and more attentions [1-3]. Examples, the wireless sensor nodes of Prometheus and Heliomote which power supply by the solar photoelectric micro-power supply were introduced [4-5]. The volume of solar photoelectric micro-power supply is larger. Bellew, et al. introduced integrated system of CMOS circuit and solar cells. In the system, the conversion efficiency of solar cells reached about 11% and output voltage of solar cells is 88V[6-7]. Others, West et al. proposed a kind the preparation method of micro lithium ion battery[8]. In the method, the solid lithium battery was deposited on chip. But, the key technology problems of integrated solar photoelectric micro-power supply on chip were not introduced in detail. In the paper, the integration scheme of the solar photoelectric micro-power supply on chip is proposed based on the structure and preparation technology of solar calls and CMOS circuit, etc. The scheme is consisted of seven main process steps and has high process compatibility. Moreover, the technology improving conversion efficiency of solar cells is proposed based on the back surfaces field (BSF).

Basis of solar photoelectric micro-power supply on chip

According to technology foundation of integrated circuit on chip, three basic principles are proposed for integrated solar photoelectric micro-power supply on chip: 1) the electric isolation between different devices. 2) the solar cells array should have high energy conversion efficiency and small size. 3) the preparation process of different devices should have high compatibility.

For studying preparation technology of integrated solar photoelectric micro-power supply on chip, the structure and material characteristics of solar cells and devices (CMOS transistor, resistor capacitor, etc) are analyzed. The Si material with the resistivity of approximately 2.5Ω.cm is chosen as devices lay on SOI wafer. Others, the relationships of thickness and conversion efficiency of Si solar cells are analyzed. The results are show in Table 1.

Table.1. Relationship of thickness and conversion efficiency of solar cells

Thickness	Conversion efficiency	Thickness	Conversion efficiency
10[μm]	8.7[%]	100[μm]	12.8 [%]
20[μm]	10 [%]	150[μm]	13.37[%]
30[μm]	10.8[%]	200[μm]	13.58[%]
40[μm]	11.4[%]	250[μm]	13.68[%]
50[μm]	11.8[%]	300[μm]	13.71[%]

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复合抛物面聚光器(CPC)在光伏/热太阳能系统中的应用及实验

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摘 要：为研究复合抛物面聚光器(compound parabolic concentrator，CPC)在光伏/热(PV/T)太阳能系统中的应用特性，分析CPC-PV/T集热器内部的热传输机理，建立CPC-PV/T太阳能系统的光热、光电能量转换理论。并对系统的光热、光电转换特性进行研究，结果表明，CPC型聚光器在PV/T系统中的应用，一定程度上会导致系统光热转换性能的降低，但能有效提高系统光电转换效率。另外，设计无聚光PV/T太阳能系统样机和CPC型聚光PV/T太阳能系统样机，并对2种样机的光热、光电特性进行测试及对比分析。其中，CPC-PV/T样机的热效率为39.6%、输出电效率5.4%，无聚光PV/T样机热效率为44%、输出电效率仅为4.1%，实验结果与理论分析结果一致。

关键词：复合抛物面聚光器（CPC）；PV/T系统；光热特性；热效率；光电特性

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0 引 言

光伏/热(PV/T)太阳能系统能同时输出电能与热能，是一个双生能系统，理论研究表明，其太阳能利用效率可达80%，但系统成本较高、实用性较差，未得到广泛推广应用[1-4]。为降低系统成本和提高太阳能的利用效率，近年来，对聚光型PV/T太阳能系统的研究得到不断增强，如Rosell等[5]介绍了一种两轴跟踪菲涅尔聚光器(11倍)与PV/T系统集成的聚光型光电/热太阳能系统，其热效率可达60%。Redpath等[6]研究热管型CPC-PV/T太阳能系统，在CPC聚光率为1.8倍条件下系统的光电转换效率增加2.5%。文献[7,8]开展对CPC-PV/T太阳能系统的理论模型分析，并对系统水流量及太阳电池覆盖率等对系统热性能的影响进行分析。另外，崔文智等[9]建立聚光型光伏/热系统的三维稳态模型，并对光电、光热转换以及流体流动和传热过程进行数值模拟。刘亚雷等[10]建立CPC-PV/T系统的动态分析模型，研究系统的结构、水流量等参数对系统性能的影响。孙 健等[11]设计CPC型低聚光PV/T单通道空气加热太阳能系统实验平台，系统的最大输出功率可达60 W，与相同电池面积无聚光系统相比，聚光系统的最大输出功率可提高20 W。

从以上分析可看出，CPC型聚光器与PV/T太阳能系统集成已得到较广泛研究，并取得了一些有益的研究成果，但针对CPC-PV/T太阳能系统工程设计及应用特性的实验研究报道较少。本文针对PV/T太阳能系统(水加热型)的结构特点，设计2倍CPC型聚光器阵列，建立CPC-PV/T系统的能量转换传输模型，对其热、电特性进行研究分析，同时，设计CPC-PV/T太阳能系统样机，并在云南楚雄对样机光热、光电特性进行测试及分析，为系统的工程化设计提供理论及实验支撑。

1 太阳电池的光热特性及CPC设计

1.1 太阳电池的光热转换特性

PV/T太阳能系统中，太阳电池能吸收超过80%入射太阳能，但仅有5%~15%的入射太阳能转换为电能，大部分吸收的太阳能被转换为热能使太阳电

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APPLICATION AND EXPERIMENT OF COMPOUND PARABOLIC CONCENTRATOR (CPC) IN PHOTOVOLTAIC / THERMAL SOLAR SYSTEM

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Abstract: In order to study the application characteristics of compound parabolic concentrator (CPC) in photovoltaic / thermal solar system, the heat transfer mechanism of the CPC-PV/T collector was analyzed, and the theoretical model of the CPC-PV/T solar system was established. The photo-thermal and photoelectric conversion characteristics of the system were studied based on the theoretical model. The results show that the application of CPC in the PV/T system can significantly improve the photoelectric conversion efficiency of the PV/T system but also reduce the heat transfer performance of the system to a certain extent. In addition, the prototypes of the non-concentrating PV/T solar system and the CPC-PV/T solar system were designed in this study. Moreover, the photo-thermal and photoelectric characteristics of two prototypes were tested and compared. The thermal efficiency and output power efficiency of the CPC-PV/T system were 39.6% and 5.4%, respectively, while that of the non-concentrating PV/T system were 44% and 4.1%, respectively. The experimental results are consistent with theoretical analysis.

Keywords: compound parabolic concentrators (CPC); photovoltaic/thermal (PV/T) system; photo- thermal characteristics; thermal efficiency; photoelectric characteristics

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摘 要 常温下，将制备好的长柄山姜及茴香砂仁的水装片放在显微拉曼光谱仪的载物台上，寻找油细胞，并分析其中精油。长柄山姜油细胞上获得的拉曼光谱，较强峰出现在1 638，1 600，1 555，1 203和1 001 cm^{-1}，次强峰出现在1 716，1 577，1 496，1 407，1 346，1 307，1 273，1 181，1 156，1 029，958，618和218 cm^{-1}共获得26条光谱线，与肉桂酸甲酯拉曼光谱的29条谱线比较，长柄山姜油细胞有22条谱线与之有对应关系；茴香砂仁油细胞上获得的拉曼光谱较强峰出现在1 648，1 639，1 607，1 174，842和836 cm^{-1}，次强峰出现在1 292，1 244，1 235，1 204和631 cm^{-1}共获得24条光谱线，与4-烯丙基苯甲醚的拉曼光谱在300～1 700 cm^{-1}区间内的29条谱线比较，茴香砂仁油细胞有23条谱峰与之有对应关系。说明长柄山姜挥发油的主要成分是肉桂酸甲酯，茴香砂仁挥发油的主要成分为4-烯丙基苯甲醚。用密度泛函理论计算了肉桂酸甲酯、4-烯丙基苯甲醚的拉曼光谱，并对谱线进行了初步的归属。姜科植物油细胞中精油不需提取就可直接快速的检测，用此方法可对姜科植物精油的提取进行质量控制及开发研究。

关键词 长柄山姜精油；茴香砂仁精油；拉曼光谱；肉桂酸甲酯；4-烯丙基苯甲醚；密度泛函理论

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引 言

长柄山姜(Alpinia kwangsiensis T. L. Wu et Senjen)及茴香砂仁(Achasma yunnanense T. L. Wu et Senjen)都属于姜科植物，长柄山姜、茴香砂仁各属山姜属及茴香砂仁属植物。都是植物药。长柄山姜根茎可治脘腹冷痛、胃寒呕吐[1]。茴香砂仁是西双版纳的一种土著植物，也是傣药品种之一(傣药名麻娘布)以根茎入药治疗小便热涩疼痛，胃脘胀痛，恶心呕吐，不思饮食，腹泻，中暑[2]。纳智利用GC-MS联用技术从长柄山姜挥发油中已鉴定出的31个成分含量，占挥发油总量的99.59%，主要成分是肉桂酸酯类、单萜烯、倍半萜烯及其含氧衍生物，其中肉桂酸甲酯占挥发油总量的94.54%；13个单萜成分占挥发油总量的3.00%，其中含量最高的是芳樟醇(0.91%)[3]。目前还未见对茴香砂仁挥发油的研究。通常用GC-MS联用技术分离鉴定挥发油中的化学组成，该方法所需要的前期样品的制备时间较长，费用高，其流程为气相色谱柱分离-质谱仪定性或定量，气相色谱分离需要在较高的温度下进行，可能会引起生物活性分子的结构改变。本课题组提出了一种不通过繁杂提取且在常温下就能进行的挥发油主要挥发性物质检测方法-样品油细胞原位显微拉曼光谱检测方法，并对姜科植物姜进行了研究，得到姜的主要挥发物为姜烯[4]。本工作利用该方法对姜科山姜属植物-长柄山姜，姜科茴香砂仁属植物-茴香砂仁的精油主要成分进行研究。

1 实验部分

长柄山姜及茴香砂仁于2015年8月采摘于西双版纳并经过专家鉴定，采用徒手切片制样后用水装片待用。分析纯的肉桂酸甲酯及4-烯丙基苯甲醚购于百灵威科技。测量仪器使用美国Thermo Fisher公司的DXR激光共焦显微拉曼光谱仪，所用的激发波长为785 nm，测定功率为2 mW，曝光时间为30 s，样品连续曝光3次。显微镜物镜倍数为20×。

对两个标样肉桂酸甲酯及4-烯丙基苯甲醚用Gaussian'03程序进行理论计算，并用RB3LYP方法(交换函数为Becke3，相关函数为LYP)在6-311G基组水平上，对其几何结构进行优化，在优化的基础上计算了振动频率，肉桂酸甲酯的计算波数在2 880～3 364 cm^{-1}之间乘以校准因子0.9572。4-烯丙基苯甲醚的计算波数乘以校准因子0.972 7。

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姜油细胞原位拉曼光谱研究

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摘 要 提出一种用拉曼光谱原位分析新鲜姜油细胞中姜油主成分的方法。用徒手切片制备新鲜姜样品，该样品置于DXR激光共焦显微拉曼光谱仪下，用20倍物镜观察到油细胞，将激光聚焦在该油细胞上，获得了姜油细胞中姜油的拉曼光谱，共21条谱峰。不同油细胞上获得的拉曼光谱非常相似。获得了姜精油的拉曼光谱，与姜精油拉曼光谱的37条谱峰比较，油细胞有19条谱峰与之有对应关系。为了解释油细胞精油及姜精油的拉曼光谱，用密度泛函理论计算了姜烯的拉曼光谱。姜精油拉曼光谱有31条谱峰，油细胞中有19条谱峰与计算光谱有对应关系。该研究提供了一种拉曼光谱技术与密度泛函理论计算结合的快速容易的精油质量控制方法。

关键词 拉曼光谱；姜油细胞；姜精油；姜烯；密度泛函理论

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引 言

姜(*Zingiber Official Rosc.*)是传统的调味料和加香剂，又是一种常用的中药，在我国广为种植。姜精油中主要成分姜烯具有多种生物活性，如抗病毒、抗溃疡和抗生育等，广泛用于化妆品和香料工业。对姜油的研究通常用GC-MS联用技术分离鉴定其中的化学组成，然而用该方法存在两个问题：一是由于提取方法的不同，使得提取到的主要的挥发性物质不同，如，崔俭杰[1]对不同产地(山东、云南、安徽、江苏、新疆)的姜油中的挥发性成分进行分析和比较，其组成成分平均含量最高为姜烯(29.7%)，其他依次为β-倍半水芹烯(12.28%)、α-姜黄烯(9.7%)；张薇[2]得出超声复合酶法提取所得姜油成分含量最高的为姜酚25.36%，其次是姜烯18.12%；超声法提取所得姜油成分含量最高的为姜烯24.41%，其次是姜酚20.14%；Singh Gurdip[3]用水蒸馏法得到姜油，分析鉴定其主要的挥发物为香叶醛(25.9%)；刘源[4]用顶空固相微萃取气质联用检测生姜挥发性成分方法得到姜的主要挥发性物质为Z—柠檬醛(24.21%)和姜烯(17.1%)；Huang[5]用同样的方法，检测用普通炉子、微波炉、硅胶干燥方法干燥的干姜挥发性成分得到姜的主要挥发性物质为姜烯(26.4%～37.1%)，β-水芹烯(7.4%～12.9%)，β-倍半水芹烯(10.2%—12.8%)，及香叶醛(6.6%～8.1%)。二是该方法所需要的前期样品的制备时间较长，费用高，其流程为气相色谱柱分离-质谱仪定性或定量，其中在进行气相色谱分离时需要在较高的温度下进行，可能会引起生物活性分子的结构改变[6]。能否不通过繁杂提取且在常温下就能进行姜油的主要挥发性物质进行检测？本文对新鲜姜采用徒手切片制样，用显微拉曼光谱直接获得了姜的油细胞中姜精油的拉曼光谱，对所获得的拉曼光谱进行了研究。文献调研结果表明，还未见这方面的报道。

1 实验部分

实验样品鲜姜于2015年7月28日采购于楚雄市菜市场，用徒手切片法制样后待用。Jofont牌水蒸馏姜精油由宏芳香料(昆山)有限公司惠赠。DXR激光共焦显微拉曼光谱仪(DXR Raman Microscope，美国Thermo Fisher)，激发波长785 nm，测定功率2 mW，曝光时间30 s，样品曝光次数3次。物镜倍数为20×。

2 计算方法

理论计算采用Gaussian'03程序，运用RB3LYP方法(交换函数为Becke3，相关函数为LYP)在6-311G基组水平上，对姜烯的几何结构进行优化，在优化的基础上计算了振

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基于顶空及表面增强拉曼散射(SERS)结合的葱属植物挥发性物质研究

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摘 要 为了在常温下鉴定新鲜植物样品的挥发性物质，且避免繁杂前期样品的制备过程，将新鲜样品切细后置入顶空瓶中，用注射器抽取顶空瓶上方的挥发性物质注入用微波法制备的纳米银溶胶中，用R-3000便携式拉曼光谱仪进行SERS的测量。获得了葱属植物大蒜、韭菜、葱的挥发性物质的表面增强拉曼光谱(SERS)。大蒜的SERS谱中较强的峰出现在307，399，569，711，1 182，1 287，1 397，1 622 cm^{-1}处。韭菜的SERS谱中最强的峰出现在672 cm^{-1}，较弱的峰出现在274，412，575，1 185，1 289，1 396，1 618 cm^{-1}处。葱的SERS谱中最强的峰出现在693 cm^{-1}，次强峰出现在372，888，1 023 cm^{-1}处，较弱的峰出现在1 088，1 211，1 322 cm^{-1}。获得二烯丙基二硫(diallyl disulfide)、烯丙基甲基硫醚(allylmethyl sulfide)、1-丙硫醇(1-Propanethiol)的液态、气态的SERS谱。经对比研究得出：吸附在银表面的大蒜、韭菜、葱的主要挥发性物质分别是二烯丙基二硫(diallyl disulfide)、烯丙基甲基硫醚(allyl methyl sulfide)、1-丙硫醇(1-Propanethiol)。同是葱属植物但不同种大蒜、韭菜、葱其吸附在银表面的主要的挥发性物质不一样，吸附在银表面的各种葱的主要挥发性物质都是1-丙硫醇。该实验结果表明顶空与SERS结合，不需要复杂的提取过程，可直接用于新鲜植物的挥发性物质快速检测。

关键词 顶空方法；SERS；葱属植物；二烯丙基二硫；烯丙基甲基硫醚；1-丙硫醇

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引 言

中国共有110种葱属植物，绝大部分的种具特殊的葱蒜气味。对其挥发性成分的研究已有很多的报道，大多是采取顶空微萃取-气相色谱/质谱联用法或气相色谱/质谱联用法，该方法可以对样品中全部或指定成分作定性和定量分析，是一种有效确定化合物分子结构的方法，并且具有灵敏度高的特点。然而，该方法所需要的前期样品的制备时间较长，费用高，其流程为微萃取—气相色谱柱分离—质谱仪定性或定量，其中在进行气相色谱分离时需要在较高的温度下进行，可能会引起生物活性分子的结构改变。从文献报道中可以看到即使是对同一种葱属植物主要挥发性物质的研究，不同文献报道得出的结论不尽相同(见表1)。这与萃取头的选取、气相色谱仪进样口的温度及解吸时间(一般在200摄氏度以上)不同有关。由于葱属植物的挥发性物质的热不稳定性，在温度较高时会发生热分解。要在室温下对葱属植物挥发性物质进行检测，必须寻找另外的方法，表面增强拉曼光谱(SERS)就是满足该条件的方法之一。

SERS在挥发性气体检测方面的文献较少，Carron[6]将SERS与气相色谱结合，获得了苯、甲苯、乙苯及二甲苯的SERS谱。为了远距离、实时、在线检测挥发性有机化合物，Mosier-Boss[7]研究小组，将表面有硫醇膜的SERS基底安装在热电冷却器上，制成传感器，用该传感器成功获得了有机氯溶剂(三氯乙烯、氯仿、全氯乙烯)、芳香族化合物(苯、甲苯、乙苯及二甲苯)、甲基叔丁基醚的SERS谱。最近，韩国首尔大学的Kwan kim等[8]将2,6-二甲基苯异腈吸附在聚乙烯亚胺包覆的纳米金上，构建传感器。当传感器探测到植物挥发性有机物，如异戊二烯、法尼醇、(+)-α-蒎烯时，2,6-二甲基苯异腈的N—C伸缩振动峰的峰位会发生移动，从而间接的检测植物挥发性有机物。目前未见用SERS技术直接研究植物挥发性有机物的报道。

用顶空(headspace)与SERS技术结合的方式，对葱属植物大蒜(garlic)、韭菜(Chinesechive)、洋葱(onion)、大葱

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Application of the screened Coulomb potential to fit the DA-type variable star HS 0507 + 0434B

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ABSTRACT

wdec is used to evolve grids of DA-variable (DAV) star models adopting the element diffusion scheme with pure and screened Coulomb potentials. The core compositions are thermonuclear burning results derived from mesa. mesa yields composition profiles that the version of WDEC used in this work could not accommodate (most notably, the presence of helium in the core of the model). According to the theory of rotational splitting, Fu and colleagues identified six triplets for the DAV star HS 0507 + 0434B based on 206 h of photometric data. The grids of DAV star models are used to fit the six reliable $m = 0$ modes. When adopting the screened Coulomb potential, a best-fitting model of $\log(M_{\rm He}/M_*) = -3.0$, $\log(M_{\rm H}/M_*) = -6.1$, $T_{\rm eff} = 11\,790$ K, $M_* = 0.625\,{\rm M}_\odot$, $\log g = 8.066$ and $\sigma_{\rm RMS} = 2.08$ s was obtained. Compared with adopting the pure Coulomb potential, the value of $\sigma_{\rm RMS}$ is improved by 34 per cent. This study may provide a new method for research into mode-trapping properties.

Key words: asteroseismology: individual (HS0507+0434B) – white dwarfs.

1 INTRODUCTION

White dwarfs are the last observable evolutionary stage of almost 98 per cent of all stars (Winget & Kepler 2008), so it is important to study them because of their wide significance. White dwarfs have masses of the order of the Sun and volumes of the order of the Earth, so they have high densities and super-gravity and are natural laboratories for the study of the extreme physical laws of super-gravity and degenerate electrons. The electron degenerate core and the ideal gas atmosphere are the basic structures of white dwarfs. White dwarfs with a H-rich atmosphere are termed DA-type white dwarfs, while DB-type white dwarfs have an atmosphere rich in He, and DO-type white dwarfs have one rich in ionized He. C and O lines are also present in the atmosphere of DO-type white dwarfs, for example in PG 1159 – 035 (Werner, Heber & Hunger 1991). The process of thermonuclear burning basically stops, and cooling (together with contraction early on) dominates the evolution of white dwarfs. Along the white dwarf cooling branch, there are DOV (DO-type variable white dwarfs), DBV and DAV instability strips. The instability strip ranges from ~170 000 to ~75 000 K for DOV stars, from ~29 000 to ~22 000 K for DBV stars, and from ~12 270 to ~10 850 K for DAV stars (Winget & Kepler 2008).

Asteroseismology is a progressive and powerful tool with which to probe the inner structure of stars. It is very important to have reliable mode identifications and physical theoretical models. In recent years, based on large telescopes, WET (Whole Earth Telescope) runs, multisite observations, and space missions such as *Kepler* and *TESS*, asteroseismological studies on white dwarfs have made considerable progress.

There are many progresses in the study of physical theoretical models. The White Dwarf Evolution Code (wdec) calculates the white dwarf cooling processes (Bischoff-Kim & Montgomery 2018). As an open-source code, wdec is very convenient for calculating grids of white dwarf models with artificial core compositions. lpcode is used to produce full evolutionary white dwarf models from the main-sequence stage. During the white dwarf evolution, the time-dependent element diffusion effect is added (see Althaus et al. 2010; Romero et al. 2012, and their recent papers). The Modules for Experiments in Stellar Astrophysics code (mesa) can evolve a star from the pre-main-sequence stage to the white dwarf stage (Paxton et al. 2011). It is also open-source software. Chen & Li (2014a) added the core compositions of white dwarfs evolved by mesa to wdec to evolve grids of white dwarf models. The thermonuclear burning core is more physical than previous artificial cores in wdec. Su et al. (2014) incorporated the scheme of Thoul, Bahcall & Loeb (1994) into wdec to treat the element diffusion of H, He, C and O. The equation of the Coulomb logarithm (equation 9 in Thoul et al. 1994) is for a pure Coulomb potential with a cutoff at the Debye radius. White dwarfs are extremely compact objects with super-gravity fields, however, so in the high-density stellar plasma environment the screened Coulomb potential may be more suitable. Paquette et al. (1986) provided a better description of the white dwarf plasma using the screened Coulomb potential.

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Application of screened Coulomb potential in fitting DBV star PG 0112+104

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ABSTRACT

With 78.7 d of observations for PG 0112+104, a pulsating DB star, from Campaign 8 of *Kepler* 2 mission, Hermes et al. made a detailed mode identification. A reliable mode identification, with 5 $l = 1$ modes, 3 $l = 2$ modes, and 3 $l = 1$ or 2 modes, was identified. Grids of DBV star models are evolved by WDEC with element diffusion effect of pure Coulomb potential and screened Coulomb potential. Fitting the identified modes of PG 0112+104 by the calculated ones, we studied the difference of element diffusion effect between adopting pure Coulomb potential and screened Coulomb potential. Our aim is to reduce the fitting error by studying new input physics. The starting models including their chemical composition profile are from white dwarf models evolved by MESA. They were calculated following the stellar evolution from the main sequence to the start of the white dwarf cooling sequences. The optimal parameters are basically consistent with that of previous spectroscopic and asteroseismological studies. The pure and screened Coulomb potential lead to different composition profiles of the C/O-He interface area. High k modes are very sensitive to the area. However, most of the observed modes for PG 0112+104 are low k modes. The $\sigma_{\rm RMS}$ taking the screened Coulomb potential is reduced by 4 per cent compared with taking the pure Coulomb potential when fitting the identified low k modes of PG 0112+104. Fitting the *Kepler* 2 data with our models improved the $\sigma_{\rm RMS}$ of the fit by 27 per cent.

Key words: asteroseismology – white dwarfs.

1 INTRODUCTION

White dwarfs are the final evolutionary state for most of low and medium mass stars, which corresponds to around 98 per cent of the end state of all stars (Winget & Kepler 2008). For most white dwarfs, the nuclear fusion has basically stopped. Therefore, the white dwarfs gradually cool down through radiating. Along the evolution track of white dwarfs in the Hertzsprung–Russel diagram, there are DOV, DBV, and DAV instability strips. The DO type white dwarfs have rich helium (He) atmosphere with strong He II lines and the DOV instability strip is basically from 170 000 to 75 000 K (Córsico, Althaus & Miller Bertolami 2006). The DB-type white dwarfs have rich He atmosphere with strong He I lines and the DBV instability strip is basically from 29 000 to 22 000 K (Beauchamp et al. 1999, Bischoff-Kim & Østensen 2011). The DA-type white dwarfs have rich hydrogen (H) atmosphere with only Balmer lines and the DAV instability strip is basically from 12 270 to 10 850 K (Gianninas, Bergeron & Fontaine 2005, Gianninas, Bergeron & Fontaine 2011).

There are now at least 20 DBV stars observed (Corsico 2009). The DBV stars can be used as an excellent probe to study the energy loss rate for plasma neutrino. The neutrino luminosity and photon luminosity have different characteristics at the blue and red ends of the DBV instability strip (Winget et al. 2004). The rate of period change for hot DBV stars, such as the DBV star EC 20058−5234 and PG 0112+104, would be closely related to the plasma reaction. With pure-He DB models, Beauchamp et al. (1999) fitted EC 20058−5234 with effective temperature of $T_{\rm eff} = 28\,400$ K and fitted PG 0112+104 with $T_{\rm eff} = 31\,500$ K.

EC 20058−5234 is the eighth DBV star found with a magnitude of $V = 15.6$ (Koen et al. 1995). Sullivan et al. (2008) presented an analysis of a total of 177 h of high-quality optical time series photometry on EC20058−5234 and identified eight independent $l = 1$ or 2, and $m = 0$ modes. The index l is the spherical harmonic degree and m is the azimuthal number. Based on those eight identified modes, they did asteroseismological study on EC 20058−5234 and then obtained optimal models with $T_{\rm eff} \sim 28\,200$ K. Their asteroseismological results are consistent with the pure He spectral fitting of $T_{\rm eff} = 28\,400$ K (Beauchamp et al. 1999). The asteroseismology method is feasible and effective for the hot DBV star.

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附件 1.

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Application of screened Coulomb potential in fitting DBV star PG 0112+104

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