

基于纤维素的可穿戴电子设备研究进展

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摘要: 综述了纤维素基可穿戴电子设备作为人体“第二皮肤”近期取得的研究进展, 尤其是在医疗保健领域, “第二皮肤”的发展和将会是人们实现健康管理和动态治疗的有效途径。指出了“第二皮肤”的固有特点: 一是能很好地与人体合二为一; 二是具有优于人体皮肤的属性。分别从可拉伸性、自供电、热管理和透气性四个方面分析了“第二皮肤”成为新一代智能健康终端的开发潜力。针对人体疾病的预防和治疗, 举例阐述了“第二皮肤”中实时监测功能所蕴含的医用价值, 同时总结了“第二皮肤”在药物输送方面所具有的独特优势。最后, 探讨了目前“第二皮肤”研究面临的挑战, 并对“第二皮肤”的发展趋势进行了展望。

关键词: 第二皮肤; 纤维素; 可穿戴电子; 柔性传感器; 医疗保健

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Research Progress of Cellulose Based Wearable

Electronic Devices

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Abstract: Recent advances in cellulose based wearable electronics as the "second skin" of the human body are reviewed, especially in the health care field, the development and application of "second skin" will be an effective way for people to achieve health management and dynamic therapy. The inherent characteristics of "second skin" are pointed out. One is its outstanding ability to integrate with the human body, the other is its performance superior to human skin. The development potential of "second skin" as a new intelligent health terminal is analyzed from four aspects of the stretchability, self power supply, thermal management and breathability. Based on the prevention and treatment of human diseases, the medical value of the real time monitoring function in "second skin" is elaborated with examples, and the unique advantages of "second skin" in drug delivery are summarized. Finally, the current challenges of "second skin" research are discussed, and the development trend of "second skin" is prospected.

Key words: second skin; cellulose; wearable electronics; flexible sensor; health care

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软体机器人研究现状

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摘要: 介绍了软体机器人的发展和研究现状, 重点总结了目前软体机器人在驱动方式、建模控制、制造工艺等方面存在的难题。其驱动方式主要有气动驱动和智能材料驱动, 介绍了各驱动方式的科学原理及典型驱动结构, 软体机器人本体结构主要采用 3D 打印技术、形状沉积法以及智能复合微结构工艺等新型工艺制成。最后阐述了目前软体机器人的建模控制方法以及应用领域, 如人机交互、物品抓持、医疗领域及野外海洋勘探, 尤其在医疗领域其具有广阔的应用前景。软体机器人是一种新型机器人, 对它的研究尚未成熟, 需从材料、结构设计、驱动、传感以及控制等方面构建出一套成熟完整的体系。

关键词: 软体机器人; 软体致动器; 智能材料; 3D 打印技术; 医疗机器人

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Research Status of the Soft Robot

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Abstract: The development and research status of the soft robot are introduced. The problems of the soft robot in driving mode, modeling control and manufacturing process are summarized emphatically. The driving mode of the soft robot mainly includes pneumatic driving and intelligent material driving. The scientific principle and typical drive structure of each driving mode are introduced. The body structure of the soft robot is mainly fabricated by new technologies, such as 3D printing technology, shape deposition method and intelligent composite microstructure process. Finally, the modeling control methods and application fields of the current soft robot are expounded, the application fields include human-computer interaction, article grasping, medical field and field marine exploration, especially in the medical field. The soft robot is a new type of robot, its research is not yet mature. It needs to construct a mature and complete system from the aspects of material, structure design, drive, sensing and control.

Key words: soft robot; software actuator; smart material; 3D printing technology; medical robot

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微针阵列干电极的研究进展

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摘要: 生物电信号与人的健康状况密切相关。如何实现长期监测心电(ECG)、脑电(EEG)、肌电(EMG)和其他各种生物电信号成为当前研究中亟待解决的难题。微针阵列干电极(MNAE)采用刺入式微针电极突破角质层高阻抗特性,有望实现连续、长期、高效的生物电信号采集。结合国内外最新研究进展,在对不同生物电极进行分类和对比的基础上,概述了MNAE在信号采集方面的优势。对MNAE使用过程中影响生物电信号采集质量的主要因素进行了分析,综述了不同种类MNAE的制作工艺、改进技术,同时指出了不同种类MNAE存在的不足,并对以后的发展趋势进行展望。

关键词: 微针阵列; 干电极; 生物电信号; 采集; 阻抗

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Research Progress of the Microneedle Array Dry Electrode

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Abstract: Biopotential signals can directly reflect the health status of the human body. How to realize long term monitoring electrocardiogram(ECG), electroencephalogram(EEG), electromyogram(EMG) and other various biopotential signals has become an urgent problem to be solved in current research. The microneedle array dry electrode (MNAE) is expected to achieve biopotential signals acquisition continuously, chronically and effectively by using penetrating microneedle electrodes to pierce into the high impedance stratum corneum. The advantages of the signal acquisition during the use of the MNAE are reviewed based on the classification and comparison of different biological electrodes through analyzing the latest research progress at home and abroad. The major influence factors on the quality of biopotential signal acquisition during the use of the MNAE are analyzed. The processes and improvement technologies of different types of MNAEs are reviewed, meanwhile their limitations are pointed out. Finally, the future development trend of MNAEs is prospected.

Key words: microneedle array; dry electrode; biopotential signal; acquisition; impedance

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基于 Quokka 优化叉指背接触太阳能电池的效率

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摘要: 叉指背接触太阳能电池因前表面无栅线所带来的高短路电流及栅线位于背面所获得的组件高密度封装的优势, 吸引了众多光伏制造者的关注。然而, 由于电池背面的 p+发射区和 n+背表面场(BSF)区呈交叉分布, 在电池制备过程中需进行掩膜技术和激光烧蚀技术的隔离, 显然增加了电池制备成本。因此, 首先选用 Quokka 软件从钝化减反层及 p+发射区占比的角度探究了优化电池效率的方向, 其次利用实验验证了结果的正确性。仿真及实验结果均表明在 n+背场区和 p+发射区分别沉积 SiO<sub>2</sub>/SiN<sub>x</sub>/SiO<sub>x</sub>N<sub>y</sub> 叠层和 Al<sub>2</sub>O<sub>3</sub>/SiN<sub>x</sub>/SiO<sub>x</sub>N<sub>y</sub> 层的钝化效果均优于不含 SiO<sub>x</sub>N<sub>y</sub> 层, 而 p+发射区与相邻的 n+背场区单元宽度越窄且 p+发射区占比越高则电池效率越高。

关键词: 叉指背接触太阳能电池; 前表面无栅线; 高密度封装; p+发射区; n+背表面场(BSF)

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Optimizing the Efficiency of Interdigitated  $\backslash$  Back  $\backslash$  Contact  
Solar Cells Based on Quokka

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Abstract: Interdigitated  $\backslash$  back  $\backslash$  contact solar cells have attracted the attention of many photovoltaic manufacturers because of the advantages for high short  $\backslash$  circuit current caused by the zero  $\backslash$  finger on the front and high density packaging of the modules with fingers located on the rear. However, due to the interdigitated distribution of p+ emitter and n+ back surface field(BSF) region on the rear of the cell, the isolation of mask technology and laser ablation technology is needed in the cell fabrication process, which obviously increases the cost. Therefore firstly, the direction of optimizing cell efficiency from the perspective of passivation antireflection layer and p+ emitter ratio was explored by the Quokka software. Secondly, the experiments were carried out to verify the correctness of the results. The simulation and experimental results show that the passivation effects of SiO<sub>2</sub>/SiN<sub>x</sub>/SiO<sub>x</sub>N<sub>y</sub> stacks and Al<sub>2</sub>O<sub>3</sub>/SiN<sub>x</sub>/SiO<sub>x</sub>N<sub>y</sub> layers deposited on n+ BSF region and p+ emitter respectively are better than that of without SiO<sub>x</sub>N<sub>y</sub> layer. The narrower the unit width between p+ emitter and n+ BSF region, and the higher the p+ emitter ratio, the higher the cell efficiency.

Key words: interdigitated  $\backslash$  back  $\backslash$  contact solar cell; zero finger on the front; high density packaging; p+ emitter; n+ back surface field(BSF)

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## Formation of the Raised Source/Drain Structure of FDSOI Devices

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**Abstract:** The formation method of the metal gate oxide semiconductor field effect transistor (MOSFET) with the raised source/drain (S/D) structure on the fully depleted silicon on insulator (FDSOI) structure by the epitaxial growth on the SOI surface was introduced. The effects of various process parameters on the epitaxial growth were studied in order to obtain uniform epitaxial morphology with proper doping concentration. Two novel approaches were proposed to control the SOI thickness, i.e. the use of a new pad oxide scheme and compensation of the SOI loss caused by the process through the epitaxial growth of a thin Si layer before the formation of the raised S/D structure. The SOI thickness can be increased by about 5 nm by using these two novel methods. The channel thickness and S/D epitaxial layer thickness of the optimized FDSOI device are about 6 nm and 20-30 nm, respectively. Finally, the influence of the epitaxial composition on device performances was also investigated.

**Key words:** fully depleted silicon on insulator (FDSOI); metal gate oxide semiconductor field effect transistor (MOSFET); raised source/drain (S/D) structure; epitaxial growth; silicon on insulator (SOI) loss

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全耗尽 SOI 器件源/漏区抬升结构的形成

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**摘要:**介绍了在全耗尽绝缘体上硅 (FDSOI) 结构上, 通过在 SOI 表面外延生长形成金属氧化物半导体场效应晶体管 (MOSFET) 源/漏区抬升结构的方法。研究了不同的工艺参数对外延生长的影响, 从而在合适的掺杂浓度下得到均匀的外延生长形貌。提出了两种新的途径来控制 SOI 的厚度: 采用一种新的方法生长垫氧层, 以及在源漏区外延生长前, 在衬底外延生长硅薄膜层, 从而补偿工艺导致的 SOI 损耗。这两种新的方法使 SOI 厚度增加了约 5 nm。工艺优化后的 FDSOI 器件沟道厚度约为 6 nm, 源漏外延层厚度为 20~30 nm。最后, 阐述了外延成分对器件电学性能的影响。

**关键词:**全耗尽绝缘体上硅 (FDSOI); 金属氧化物半导体场效应晶体管 (MOSFET); 源/漏区抬升结构; 外延生长; 绝缘体上硅(SOI)损耗

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ZnO 纳微分级结构的形貌调控及其气敏性能

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摘要: 采用水热法, 通过调控反应温度得到了具有不同微观形貌的 ZnO 纳微分级结构。扫描电子显微镜(SEM)结果表明, 纳微分级结构分别由纳米棒或纳米片按不同方式堆积而成。X 射线衍射(XRD)结果表明, 所制备的 ZnO 纳微分级结构均为纤锌矿结构。此外, 通过 BET 比表面积测试与气敏性能测试发现, 微观形貌不同的分级结构具有不同的比表面积、孔隙率和平均孔径, 同时气敏性能也有差异。在反应温度为 65、100 和 150 °C 下制备了样品 S1、S2 和 S3。相比另外两组样品, 纳米片堆积而成的样品 S2 具有更大的比表面积(411.87 m<sup>2</sup>/g)、更高孔隙率(0.0926 cm<sup>3</sup>/g)和更大平均孔径(76 nm), 其最佳测试温度为 300 °C, 在三个样品中最低(S1 的最佳检测温度为 370 °C, S3 的最佳检测温度为 394 °C)。同时在最佳检测温度下 S2 对气体响应值最高(110), 响应时间最短(7.10 s)。由此说明, 高比表面积和孔隙率有利于气体的扩散, 从而能够提高材料的气敏性能。

关键词: 水热法; ZnO; 分级结构; 气体扩散; 气敏

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Morphology Control and Gas Sensing Properties of

ZnO Nano // Micro Hierarchical Structures

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Abstract: Using the hydrothermal method, ZnO nano // micro hierarchical structures with different morphologies were obtained by controlling reaction temperatures. The scanning electron micro // scopy(SEM) results show that the corresponding nano // micro hierarchical structures are composed of nanorods or nanosheets deposited in different ways. The X // ray diffraction(XRD) results indicate that the prepared ZnO nano // micro hierarchical structures have wurtzite structure. Furthermore, the results of the BET specific surface area test and gas sensing property test show that the ZnO nano // micro hierarchical structures with different morphologies have different specific surface areas, porosities and average pore sizes, meanwhile their gas sensing properties are also different. Samples S1、S2 and S3 were synthesized at 65, 100 and 150 °C, respectively. Compared with the other two samples, the sample S2 deposited by nanosheets has larger specific surface area (411.87 m<sup>2</sup>/g), higher porosity (0.0926 cm<sup>3</sup>/g) and larger average pore size (76 nm), and its optimum detection temperature is 300 °C, which is the minimum value among those of the three samples (the optimum detection temperature of S1 is 370 °C, the optimum detection temperature of S3 is 394 °C). At the optimum detection temperature, the sample S2 has the highest gas response value (110) and minimal response time(7.10 s). It is proved that large specific surface area and high porosity are beneficial to gas diffusion, and then improve gas sensing properties of materials.

Key words: hydrothermal method; ZnO; hierarchical structure; gas diffusion; gas sensing

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氧化锌薄膜体声波谐振器制作重复性和均匀性

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摘要: 通过磁控溅射靶材的成分调控和一系列优化过的微电子机械系统(MEMS)工艺, 成功研制了基于氧化锌(ZnO)压电薄膜的固体装配型薄膜体声波谐振器(FBAR)。通过使用性能优异的靶材, 所得到的器件谐振性能良好。在同一种工艺条件下得到多个硅片的中心处 FBAR 的谐振频率为  $2 \parallel 365 \sim 2 \parallel 379$  GHz, 具有较好的重复性。并且, 同一硅片不同位置的器件性能还具有优异的均匀性, S<sub>11</sub> 的平均相对误差很小。尤其谐振频率可以控制在  $2 \parallel 359 \sim 2 \parallel 410$  GHz, 相比之前的  $1 \parallel 8 \sim 2 \parallel 4$  GHz, 其均匀性有了明显的提升。同一硅片上 9 个 FBAR 谐振频率的平均相对误差能够低至  $0 \parallel 256\%$ 。

关键词: 薄膜体声波谐振器(FBAR); 氧化锌(ZnO); 谐振频率; 射频磁控溅射; 集成电路

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Process Repeatability and Uniformity of ZnO  $\parallel$  Based FBARs

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Abstract:The solid  $\parallel$  mounted film bulk acoustic resonator (FBAR) based on zinc oxide (ZnO) piezoelectric film was successfully developed by the composition control of magnetron sputtering target and a series of optimized micro  $\parallel$  electromechanical system (MEMS) processes. The fabricated device has outstanding resonance performances by using a target with excellent performances. The resonance frequencies of the FBARs at the center of some Si wafers obtained under the same process condition are  $2 \parallel 365-2 \parallel 379$  GHz, indicating that the device performances have good repeatability. In addition, the performances of the devices for the same Si wafer at different positions have good uniformity, and the average relative error of the S<sub>11</sub> is small. In particular, the resonant frequency can be controlled at  $2 \parallel 359-2 \parallel 410$  GHz, which has a significant improvement in uniformity compared with the previous  $1 \parallel 8-2 \parallel 4$  GHz. The average relative error of the resonant frequencies for 9 FBARs in the same Si wafer can be as low as  $0 \parallel 256\%$ .

Key words:film bulk acoustic resonator(FBAR); zinc oxide(ZnO); resonant frequency; radio frequency magnetron sputtering; integrated circuit

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用于流速测量的微型力传感器的研制

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摘要: 设计并仿真了一种压阻式六自由度力传感器及其测量电桥, 采用微电子机械系统 (MEMS) 加工技术制备了以单晶硅为结构材料的六自由度力传感器, 完成了传感器芯片的封帽式封装。压阻式六自由度力传感器的尺寸为  $5\text{ mm} \times 5\text{ mm} \times 3\text{ mm}$ , 由传感器芯片、探测柱和封装外壳组成。基于流体的绕流阻力效应, 完成了压阻式六自由度力传感器水流流速检测实验。实验证明, 该传感器的量程为  $0 \sim 0 \parallel 55\text{ m/s}$ , 可以灵敏检测到低速水流的波动性变化, 并且传感器在水流速度为  $0 \parallel 45 \sim 0 \parallel 55\text{ m/s}$  的测量范围内灵敏度较高。利用单晶硅材料易于小型化、滞后极小的特点, 该六自由度力传感器响应快、环境适应性强、可批量制造。

关键词: 微电子机械系统 (MEMS); 六自由度 (6 卍 DOF); 力传感器; 封装; 流速传感器  
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Fabrication of Micro Force Sensor for Flow Velocity Measurement

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Abstract: A piezoresistive 6 卍 degree of freedom (6 卍 DOF) force sensor and its measuring bridge were designed and simulated. A 6 卍 DOF force sensor with monocrystalline silicon as its structural material was fabricated by micro 卍 electromechanical system (MEMS) processing technology, and the sealing cap package of the sensor chip was completed. The piezoresistive 6 卍 DOF force sensor is  $5\text{ mm} \times 5\text{ mm} \times 3\text{ mm}$  in size and consists of a sensor chip, a probe column and a packaging shell. Based on the flow around resistance effect of the fluid, the flow velocity detection experiments of the piezoresistive 6 卍 DOF force sensor were carried out. The experimental results show that the sensor has a range of  $0 \sim 0 \parallel 55\text{ m/s}$ , and can sensitively detect the fluctuation change of low 卍 speed water flow. Moreover, the sensor has a high sensitivity in the flow velocity measurement range of  $0 \parallel 45 \sim 0 \parallel 55\text{ m/s}$ . Using the characteristics of monocrystalline silicon material, such as easy miniaturization and minimal lag, the 6 卍 DOF force sensor has fast response, strong environmental adaptability, and can be achieved batch manufacturing.

Key words: micro 卍 electromechanical system (MEMS); six degrees of freedom (6 卍 DOF); force sensor; package; flow velocity sensor

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空心硅通孔的设计及其传输性能

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摘要: 硅通孔(TSV)能够实现信号的垂直传输, 是微系统三维集成中的关键技术, 在微波毫米波领域, 硅通孔的高频传输特性成为研究的重点。针对微系统三维集成中, 无源集成的硅基转接板的空心 TSV 垂直传输结构低损耗的传输要求, 进行硅通孔的互连设计和传输性能分析。采用传输线校准方式, 首先在硅基转接板上设计 TSV 阵列接地的共面波导(CPW)传输线和带 TSV 过孔的传输结构, 并分别进行仿真分析, 计算得出带 TSV 过孔的传输结构的插入损耗; 然后通过后道 TSV 工艺, 在硅基转接板上制作传输线和带 TSV 过孔的传输结构, 用矢量网络分析仪法测试传输线和带 TSV 过孔的传输结构的插入损耗; 最后计算得到单个 TSV 过孔的插入损耗, 结果显示在 0 ~ 30 GHz 频段内其插入损耗  $S_{21} \leq 0 \pm 1$  dB, 实现了基于 TSV 的低损耗信号传输。

关键词: 微系统; 三维集成; 硅通孔(TSV); 射频(RF)传输; 低插入损耗

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Design and Transmission Performance of the Hollow Through Silicon Via

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Abstract: The through silicon via (TSV) can realize signal vertical transmission, which is the key technology of 3D integration for microsystems. In the field of microwave and millimeter wave, high frequency transmission performance of the TSV becomes the research focus. In order to meet the low loss transmission requirements of the hollow TSV vertical transmission structure in the silicon interposer with integrated passive devices for the microsystem 3D integration, the interconnection design and transmission performance analysis of the TSV were carried out. By using the calibration method of the transmission line, the TSV array grounded coplanar waveguide (CPW) transmission line and transmission structure with TSVs were designed firstly on the silicon interposer, and the simulation analyses were carried out respectively to calculate the insertion loss of the transmission structure with TSVs. Then the transmission line and transmission structure with TSVs were made on the silicon interposer by the TSV via last process, and the insertion loss of the transmission line and transmission structure with TSVs were measured by using the vector network analyzer method. Finally, the insertion loss of the single TSV was calculated. The result shows that the insertion loss  $S_{21} \leq 0 \pm 1$  dB within the frequency band of 0 ~ 30 GHz, indicating that the low insertion loss of the signal transmission based on the TSV is realized.

Key words: microsystem; 3D integration; through silicon via (TSV); radio frequency(RF) transmission; low insertion loss

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TiO<sub>2</sub> 的制备及其在钙钛矿太阳能电池中的应用

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摘要: 分别采用溶液法和磁控溅射法制备了 TiO<sub>2</sub> 薄膜。其中对采用磁控溅射法制备的样品进行了退火。用扫描电子显微镜 (SEM) 观察了薄膜的表面形貌, 表征结果发现, 与溶液法制备的 TiO<sub>2</sub> 薄膜相比, 采用磁控溅射法制备的薄膜更加致密, 表面粗糙度更低。X 射线衍射 (XRD) 测试结果说明, 溶液法制备的薄膜是多晶结构, 而磁控溅射制备的薄膜是非晶结构, 经过 500 °C 退火后溅射的样品也只有一个 (101) 峰。在制备好的 TiO<sub>2</sub> 薄膜上旋涂钙钛矿层, 将其制备成太阳能电池, 并测试其光电性能。I-V 曲线表明, 采用磁控溅射法制备的 TiO<sub>2</sub> 薄膜制备的电池具有更高的开路电压。

关键词: TiO<sub>2</sub> 薄膜; 太阳能电池; 磁控溅射法; 溶液法; 电流-电压法

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Preparation of Titanium Dioxide and Its

Application in Perovskite Solar Cells

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Abstract: Titanium dioxide (TiO<sub>2</sub>) thin films were prepared separately by the solution method and magnetron sputtering method. The samples prepared by the magnetron sputtering method were thermally annealed. The surface morphologies of the thin films were observed by the scanning electron microscopy (SEM). The characterization results show that comparing with the TiO<sub>2</sub> thin film prepared by the solution method, the thin film prepared by the magnetron sputtering method is more dense and has a lower surface roughness. X-ray diffraction (XRD) results show that the thin film prepared by the solution method is polycrystalline, while the thin film prepared by the magnetron sputtering method is amorphous, and the sample sputtered after the anneal at 500 °C has only one (101) peak. Then, a perovskite layer was spin coated on the prepared TiO<sub>2</sub> thin film, then a solar cell was prepared, and photoelectric properties of the solar cell were tested. I-V curve indicates that the cell prepared with the sputtered TiO<sub>2</sub> film has a higher open circuit voltage.

Key words: TiO<sub>2</sub> thin film; solar cell; magnetron sputtering method; solution method; current-voltage method

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铜互连 CMP 中 BTA 的缓蚀机理及

Cu Ⅱ BTA 的去除研究进展

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摘要: 铜具有低电阻率和高抗电迁移性, 是目前极大规模集成电路的主流金属互连材料。化学机械抛光(CMP)是实现铜表面局部与全局平坦的关键工艺。为获得铜互连较高的凹凸材料去除速率选择比, 通常需在 CMP 抛光液中加入缓蚀剂苯并三唑(BTA), 而 CMP 后铜表面的 BTA 残留需要在后续的清洗工艺中进行有效的去除。对铜互连 CMP 中 BTA 对铜的腐蚀抑制机理的研究进行了归纳分析, 并对 BTA 与其他试剂协同抑制铜腐蚀的研究进行了讨论, 进而论述了碱性清洗液对 Cu Ⅱ BTA 络合物去除的研究进展, 并概述了新型缓蚀剂的研究现状, 最后对缓蚀剂未来的研究方向进行了展望。

关键词: 苯并三唑(BTA); 铜; 缓蚀; Cu Ⅱ BTA; 化学机械抛光(CMP)

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Research Progress on Corrosion Inhibition Mechanism of BTA in

Copper Interconnection CMP and Removal of Cu Ⅱ BTA

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Abstract: Because of its low resistivity and high resistivity to electromigration, copper has become the mainstream metal interconnection material for large scale integrated circuits. Chemical mechanical polishing (CMP) is a key technology to achieve local planarization and overall planarization of copper surface. In order to obtain higher removal rate selectivity of concave and convex materials for copper interconnection, the corrosion inhibitor benzotriazole (BTA) is usually added to CMP slurry, and the BTA residue on the copper surface after CMP needs to be effectively removed in subsequent cleaning process. The researches of copper corrosion inhibition mechanism by the BTA in copper interconnection CMP are summarized and analyzed. The researches for synergistic inhibition of copper corrosion by the BTA and other reagents are also discussed. Furthermore, the research progress of removal of Cu Ⅱ BTA complex by alkaline cleaning solution is discussed. The research status of new corrosion inhibitors is overviewed. Finally, the future research directions of corrosion inhibitors are prospected.

Key words: benzotriazole(BTA); copper; corrosion inhibition; Cu Ⅱ BTA; chemical mechanical polishing (CMP)

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## 4HN Ⅱ SiC 包裹物在薄层同质外延中的转化

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摘要: 对 4HN 型碳化硅(4HN Ⅱ SiC)包裹物进行了系统的研究, 首次提出了包裹物分布的碳氮竞位模型, 并对各种包裹物的起源及抑制改善提出了有效的解决方法。同时研究了 4HN 型 SiC 包裹物在薄层同质外延过程中的转化, 发现外延后包裹物主要转化为三角形、凸起和凹坑三种表面缺陷。对比外延前后缺陷形貌发现, 包裹物外延后呈现的表面缺陷类型主要取决于包裹物的大小和聚集密度。在工艺优化过程中, 发现低碳硅比环境下来源于包裹物的表面“杀手级”缺陷数量明显降低。这是由于随着碳硅比的降低, 外延过程中台阶流生长占主导, 减少了岛状成核点。通过对生长单晶抛光片和外延片工艺的优化, 制备出外延后无包裹物导致的表面“杀手级”缺陷的高质量 4HN Ⅱ SiC 外延片, 其合格率达到 99 % 3%。

关键词: 4HN 型碳化硅; 碳氮竞位; 包裹物; 表面缺陷; 外延

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### Conversion of 4HN Ⅱ SiC Inclusions in the Thin Layer Homogeneous Epitaxy

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Abstract:The inclusions of 4HN type silicon carbide (4HN Ⅱ SiC) were systematically studied, a model of carbon nitrogen competition for inclusion distribution was firstly provided, and an effective solution method to the origin and inhibition of various inclusions was proposed. Meanwhile, the conversion of 4HN Ⅱ SiC inclusions in the thin layer homogeneous epitaxial process was studied. It is found that the inclusions after epitaxy are mainly transformed into the three kinds of surface defects: triangle, bulge and pit defects. Comparison results of the defect morphologies before and after epitaxy show that the surface defect type of inclusions after epitaxy depends on the size and packing density of inclusions. It is observed that the surface killer defects resulting from the inclusions can be obviously suppressed under the lower carbon silicon ratio condition in the optimization process. The reason is that the step flow growth takes the dominant role and island nucleation site is reduced in the epitaxial process under the condition of lower carbon silicon ratio. By the growth processing optimization of single crystal polished wafers and epitaxial wafers, a high quality 4HN Ⅱ SiC homoepitaxial wafer without the killer defects induced by the inclusions was obtained. And its yield reaches 99 % 3%.

Key words:4HN type silicon carbide(4HN Ⅱ SiC); carbon nitrogen competition; inclusion; surface defect; epitaxy

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离子注入技术在单晶硅太阳能电池上的应用

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摘要: 采用 Silvaco 的 TCAD 仿真软件模拟了在一定注入能量下离子注入剂量、退火温度和时间对太阳能电池表面方块电阻和结深的影响, 并通过离子注入机和高温退火炉进行了实验验证。实验结果表明, 当离子注入剂量为  $7 \times 10^{14} \text{ cm}^{-2}$ 、注入能量为 10 keV、退火时间为 20 min、退火温度为  $870 \sim 890 \text{ }^\circ\text{C}$  时, 电池表面方块电阻超过  $130 \text{ } \Omega/\square$ , 均匀性良好, 结深可达  $0 \sim 6 \text{ } \mu\text{m}$ 。当离子注入剂量小于  $7 \times 10^{14} \text{ cm}^{-2}$  时, 方块电阻值过大, 且均匀性较差。均匀性良好的高方块电阻可有效降低电池表面的少子复合, 进而有助于提升电池效率。

关键词: 离子注入; 太阳能电池; 退火; 方块电阻; 结深

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Application of the Ion Implantation Technology in

Monocrystalline Silicon Solar Cells

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Abstract: Silvaco's TCAD simulation software was used to simulate the effects of the ion implantation dose, annealing temperature and time on the surface sheet resistance and junction depth of the solar cell at a certain implantation energy, which were verified by the experiment with the ion implantation machine and high temperature annealing furnace. The experimental results show that when the ion implantation dose is  $7 \times 10^{14} \text{ cm}^{-2}$ , the implantation energy is 10 keV, the annealing time is 20 min and the annealing temperature is between  $870 \text{ }^\circ\text{C}$  and  $890 \text{ }^\circ\text{C}$ , the surface sheet resistance of the cell exceeds  $130 \text{ } \Omega/\square$  and is of good uniformity, and the junction depth can reach  $0 \sim 6 \text{ } \mu\text{m}$ . When the ion implantation dose is less than  $7 \times 10^{14} \text{ cm}^{-2}$ , the sheet resistance is too large and the uniformity is poor. High sheet resistance with good uniformity can effectively reduce the minority carrier recombination of the cell surface, which is helpful to improve the solar cell efficiency.

Key words: ion implantation; solar cell; annealing; sheet resistance; junction depth

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