

## 纳电子学与神经形态芯片的新进展

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**摘要:** 综述了纳电子学和神经形态芯片进入新世纪后所处发展阶段以及近两年的最新进展。在纳电子领域, 综述并分析了当今集成电路的发展现状, 包括鳍式场效应晶体管(FinFET)的发展、10 nm 节点的技术突破、7 nm 和 5 nm 节点的前瞻性技术研究以及三类后互补金属氧化物半导体(CMOS)器件(自旋电子器件、隧穿 FET 和碳纳米管栅的二维半导体 MoS<sub>2</sub> 晶体管)的探索性研究, 指出摩尔定律将沿着加强栅对沟道电子的控制(三栅和环栅)、更换高迁移率材料和采用新机理等技术路线继续前行。在神经形态芯片领域, 综述并分析了神经形态芯片的发展历程、“真北”类脑芯片的技术创新和应用、当今嵌入式神经处理器的四个发展特点和采用新器件提高能量效率的探索。采用纳电子技术的神经形态芯片的发展将成为未来智能时代发展的基础。

**关键词:** 纳电子学; 鳍式场效应晶体管(FinFET); 10 nm 互补金属氧化物半导体(CMOS); 纳米线晶体管; 自旋电子学; 碳纳米管栅; 神经形态芯片; 类脑芯片; 神经形态处理器; 忆阻器

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New Progress of Nanoelectronics and Neuromorphic Chips

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**Abstract:** The development phase of nanoelectronics and neuromorphic chips after entering the new century and the latest developments in the past two years are reviewed. In the field of the nanoelectronics, the development status of the integrated circuits today is reviewed and analyzed, including the developments of Fin field effect transistors(FinFETs), the technology breakthrough in 10 nm node, the forward looking technology research in 7 nm node and 5 nm node, the exploratory studies of three types of beyond complementary metal oxide semiconductor transistor (CMOS) devices (spin electronics devices, tunneling FETs and carbon nanotubes gate/ two dimensional MoS<sub>2</sub> semiconductor transistors). It point out that Moore's law will keep on moving with the technical route of strengthening the gate control for the channel electrons (3 gate and ring gate), using high mobility materials, adopting new mechanism and so on. In the field of neuromorphic chips, the developing courses of neuromorphic chips, the technology innovation and application of "true north" brain chips, the four development characteristics of current embedded nerve processors and the exploration of the energy efficiency improved by adoption of new devices are reviewed and analyzed. The development of neuromorphic chips using nanoelectronic technology will be a foundation of future intelligent era development.

**Key words:** nanoelectronics; Fin field effect transistor(FinFET); 10 nm complementary metal oxide semiconductor (CMOS); nanowire transistor; spintronics; carbon nanotube gate; neuromorphic chip; class brain chip; neuromorphic processor; memristor

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基于量子元胞自动机的新型同或门结构设计

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摘要: 由于互补金属氧化物半导体 (CMOS) 器件尺寸的限制, 量子元胞自动机 (QCA) 成为有望替代 CMOS 的新兴纳米器件。量子元胞自动机具有超低功耗、超高速度和高密度结构的潜在优势。提出了一种新型的同或门结构, 在面积、延迟、复杂度及功耗方面相较于之前的结构均存在优势。所提出的新型同或门结构仅使用 28 个面积为  $0.02 \mu\text{m}^2$  的 QCA 元胞, 延迟仅为 0.75 个时钟周期。为了检验提出的设计在大型复杂 QCA 电路中的性能, 实现了 4, 8 和 16 位的奇偶校验器电路。模拟结果表明, 所设计的电路性能各方面均优于先前的设计。

关键词: 量子元胞自动机 (QCA); 五输入择多门; 同或门; 异或门; 奇偶校验器; 性能分析

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Structure Design of the New XNOR Gate Based on the  
Quantum Cellular Automata

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Abstract: Due to the size limitation of complementary metal oxide semiconductor (CMOS) devices, a quantum cellular automata (QCA) becomes a new nanometer device that is expected to replace CMOS devices. QCA has the potential advantages of ultra low power consumption, ultra high speed and high density structure. A novel XNOR structure with advantages compared to the previous structure was proposed, including area, delay, complexity and power consumption. The proposed XNOR structure used only 28 QCA cells with an area of  $0.02 \mu\text{m}^2$ . The delay of the structure was only 0.75 clock cycles. In order to check the efficiency of the proposed design in the large and complex QCA circuit, the parity check device circuits with 4, 8 and 16 bits lengths were implemented. The simulation results show that the performance of the designed circuit are better than that of the previous designs.

Key words: quantum cellular automata (QCA); five input majority gate; XNOR gate; XOR gate; parity check device; performance analysis

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## TiO<sub>2</sub> 薄膜染料敏化太阳能电池的性能

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摘要: 采用旋涂法、提拉法、水热法、涂覆法制备了 TiO<sub>2</sub> 薄膜, 利用紫葡萄皮染料分子敏化了 TiO<sub>2</sub> 薄膜电极, 制备出太阳电池。测试结果表明涂覆法制备的太阳电池的效率最好, 初始短路电流密度、开路电压分别为 2 840 mA/cm<sup>2</sup> 和 0 594 mV, 而稳定性最差。相同条件下, 其电池短路电流密度、开路电压与初始短路电流密度、开路电压的偏差百分比分别为 13 3%和 10%。旋涂法、提拉法、水热法制备的电池初始短路电流密度分别为 0 619, 1 071 和 0 901 mA/cm<sup>2</sup>, 初始开路电压分别为 0 447, 0 481 和 0 488 mV, 稳定性基本一样, 短路电流密度与初始短路电流密度的偏差百分比分别为 9 3%, 9 8% 和 9 3%, 开路电压与初始开路电压的偏差百分比分别为 8 2%, 7 3%和 6 9%。电池的不稳定性在初期很强, 衰退很快, 后期趋于缓和。

关键词: TiO<sub>2</sub> 薄膜; 天然染料; 太阳电池; 紫葡萄皮; 稳定性

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Properties of Dye Sensitized Solar Cells Based on TiO<sub>2</sub> Thin Films

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Abstract: The TiO<sub>2</sub> thin films were prepared by the spin coating method, Czochralski method, hydrothermal method and coating method. The TiO<sub>2</sub> thin film electrodes were sensitized by dye molecules of the purple grape skin, and then the solar cells were prepared. The test results show that the efficiency of the solar cell prepared by the coating method is the best. The initial short circuit current density and open circuit voltage are 2 840 mA/cm<sup>2</sup> and 0 594 mV respectively, and the stability is the worst. Under the same conditions, the deviation percentages of the short circuit current density and open circuit voltage of the cell from those under the initial condition are 13 3% and 10%, respectively. For the cells prepared by the spin coating method, Czochralski method and hydrothermal method, the initial short circuit current densities are 0 619, 1 071 and 0 901 mA/cm<sup>2</sup> respectively, the initial open circuit voltages are 0 447, 0 481 and 0 488 mV respectively, and the stabilities are basically the same. Moreover, the deviation percentages of the initial short circuit current density from those under the initial condition are 9 3%, 9 8% and 9 3% respectively, and the deviation percentages of the initial open circuit voltage from those under the initial condition are 8 2%, 7 3% and 6 9% respectively. The instabilities of the cells are very strong at the early stage, decline very fast, and tend to relax at the later stage.

Key words: TiO<sub>2</sub> thin film; natural dye; solar cell; purple grape skin; stability

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电子封装用金属基复合材料的研究现状

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摘要: 介绍了典型的电子封装用复合材料, 着重介绍了不同类型的金属基复合材料(MMC); 综述了以铝碳化硅(SiC/Al)和 Si/Al 为代表的金属基复合材料的国内外研究现状和进展, 阐述了 SiC/Al 复合材料常见的制备工艺, 比较了粉末冶金、铸造法、喷射沉积、浸渗法等不同制备工艺的优缺点并讨论了不同制备工艺的影响因素, 分析了这些工艺所制备的复合材料的热膨胀系数和热导率等热物理性能; 介绍了 SiC/Al 复合材料在国内外航空航天、飞行器、民用汽车和光电子器件等领域的应用实例, 在此基础上指出了目前研究还需解决的基础理论研究 and 多学科交叉等问题, 展望了 SiC/Al 复合材料未来的研究和发展方向。

关键词: 电子封装; 金属基复合材料 (MMC); 铝碳化硅; 热膨胀系数; 热导率

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Research State of Metal Matrix Composites for Electronic Packaging

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Abstract: Typical electronic packaging composites are introduced, and the different kinds of metal matrix composites (MMCs) are emphatically introduced. The domestic and overseas research state and progress of MMCs represented by SiC/Al and Si/Al are reviewed. The common manufacturing process of the SiC/Al composites is expounded. The advantages and disadvantages of different manufacturing processes are compared, such as powder metallurgy, casting process, spray deposition and impregnation method, and their influencing factors are discussed. The thermophysical characteristics of the composites prepared by the manufacturing processes, including coefficient of thermal expansion, thermal conductivity and so on, are analyzed. The domestic and overseas research application examples of the SiC/Al composites in fields of aerospace, aircraft, civilian automobile and optoelectronic devices are also introduced. On this basis, the problems of basic theory research and multi subject crossing in the present research are pointed, and the future research and develop directions of the SiC/Al composites are prospected.

Key words: electronic packaging; metal matrix composite (MMC); SiC/Al; coefficient of thermal expansion; thermal conductivity

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具有微生物颗粒预富集功能的微过滤系统设计

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摘要: 为了提高微流式细胞仪对低浓度细胞样本液的检测效率和准确率, 提出一种以电磁驱动的微过滤系统设计方案。该微过滤系统包括具有过滤结构的微流控芯片(微过滤芯片)和电磁驱动机构, 借助电磁控制来实现微过滤芯片对微生物颗粒的富集功能。使用微电子机械系统(MEMS)工艺设计与制作了聚二甲基硅氧烷(PDMS)薄膜微过滤芯片, 通过对微过滤芯片的受力分析, 自制了一套电磁驱动装置。使用溶有直径为 30 μm 荧光微球的去离子水溶液(荧光微球与去离子水的体积比 1:40)对微过滤系统样机进行功能测试, 通过控制电流大小、通电时间对给定溶液中的荧光微球实现了预富集效果。测试结果表明该微过滤系统设计合理, 具有制作简单, 成本低、易于集成等优点, 能够在医学检测中广泛应用。

关键词: 预富集; 过滤; 微流控芯片; 聚二甲基硅氧烷(PDMS); 电磁驱动

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Design of a Microfilter System for Microbiological

Particle Preconcentration

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Abstract: In order to improve the testing efficiency and accuracy of the cell sample solution with low concentration using the microfluidic cytometer, a design scheme of the electromagnetic drive microfilter system was presented. The microfilter system consisted of the microfluidic chip with the filtering structure (microfilter chip) and electromagnetic drive device, and the microbial particle enrichment function of the microfilter chip was realized with the help of the electromagnetic control. The micro electromechanical system(MEMS) technology was used to design and fabricate the polydimethylsiloxane (PDMS) membrane microfilter chip. Through the force analysis of the microfilter chip, the electromagnetic drive device was fabricated. The microfilter system prototype was tested using the deionized water solution with 30 μm diameter fluorescent microsphere (the volume ratio of the fluorescent microsphere and deionized water was 1:40), the preconcentration effect of the fluorescent microsphere in the solution was achieved by controlling the current and conduction time. The test results show that the design of the microfilter system is reasonable, has advantages of simple fabrication process, low production cost and ease of integration, and can be widely applied in the medical testing.

Key words: preconcentration; filter; microfluidic chip; polydimethylsiloxane (PDMS); electromagnetic drive

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## 基于四螺旋梁-质量块的 MEMS 压电能量采集器

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**摘要:**设计了一种四螺旋悬臂梁-质量块结构的压电能量采集器,将环境振动能转换为电能。采用有限元分析软件 (COMSOL Multiphysics) 建立结构模型,仿真结构固有频率,计算不同振动频率下器件的位移、应力、应变和电势以及不同加速度下的电压输出,仿真得到结构的一阶谐振频率为 102 Hz,为后期测试提供指导。利用溶胶-凝胶工艺完成锆钛酸铅 (PZT) 压电薄膜的制备,通过微电子机械系统 (MEMS) 工艺和引线键合工艺完成器件结构制造,将四个螺旋梁上的压电单元串联以实现输出最大化。性能测试结果表明:器件固有频率为 110 Hz,输出电压随加速度的增大而线性增大,3g 加速度下输出电压峰峰值为 140 mV。

**关键词:** 微电子机械系统 (MEMS); 压电效应; 锆钛酸铅 (PZT); 能量采集器; COMSOL

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MEMS Piezoelectric Power Generator Based on the Four Helical  
Cantilever Beam Mass Block

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**Abstract:**A piezoelectric power generator based on the four helical cantilever beam mass block was designed to convert environmental vibration energy into electrical energy. The finite element analysis software (COMSOL Multiphysics) was used to build the structural model, simulate the inherent frequency of the structure, calculate the displacement, stress, strain and potential of the device under different vibration frequencies and the output voltage under different accelerations. The simulation results show that the first order resonant frequency of the structure is 102 Hz, providing a guidance for the later test. The PbZrO<sub>3</sub>TiO<sub>4</sub>7O<sub>3</sub>(PZT) piezoelectric thin film was fabricated by the sol gel method. The device structure was fabricated through the micro electromechanical system(MEMS) process and wire bonding process. The piezoelectric elements on the four helical beams were connected in series to maximize the output. The performance test results show that the inherent frequency of the device is 110 Hz, the output voltage increases linearly with the increase of the acceleration, and the output voltage peak to peak value is 140 mV at 3g acceleration.

**Key words:**micro electromechanical system(MEMS); piezoelectric effect; PbZrO<sub>3</sub>TiO<sub>4</sub>7O<sub>3</sub>(PZT); power generator; COMSOL

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## 全解耦硅 MEMS 陀螺仪正交耦合分析

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摘要: 为了减小正交误差对硅 MEMS 陀螺仪性能的影响, 进一步提高陀螺精度和工程化成品率, 对 MEMS 陀螺正交耦合的影响因素进行了研究。通过 MEMS 陀螺的运动学简化模型, 分析了正交耦合的起因; 计算了 MEMS 陀螺的静电驱动力和阻尼系数, 建立了 MEMS 陀螺有限元参数化模型, 利用谐波分析模拟了陀螺在驱动模式下的运动状态; 在谐波分析的基础上, 研究了不同误差来源对正交耦合的影响。结果表明: 侧壁垂直度误差不是正交耦合的起因; 科氏质量重心偏移对正交耦合的影响很小, 即使在误差敏感方向上, 正交耦合系数的敏感度也只有  $0.0032\%/ \mu\text{m}$ ; 振动结构支撑梁的加工误差是引起结构刚度不对称并产生正交耦合的主要因素, 其中正交耦合系数对梁宽误差的敏感度可达  $2.15\%/ \mu\text{m}$  (梁宽误差为  $\pm 0.1 \mu\text{m}$ ), 对梁倾斜误差的敏感度高达  $16\%/(\circ)$  (梁角度误差为  $\pm 0.05^\circ$ )。

关键词: 微电子机械系统 (MEMS); 陀螺仪; 静电驱动; 正交耦合; 有限元分析 (FEA)

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Orthogonal Coupling Analysis of a Fully Decoupled

Silicon MEMS Gyroscope

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Abstract: In order to reduce the influence of the orthogonal error on the performance of silicon MEMS gyroscope and improve the gyroscope accuracy and engineering yield rate, the influence factors of the orthogonal coupling of the MEMS gyroscope were studied. The cause of the orthogonal coupling was analyzed using a MEMS gyroscope simplified kinematic model. Through calculating the electrostatic driving force and damping coefficient of the MEMS gyroscope, the MEMS gyroscope finite element parametric model was established, and the motion state of the gyroscope in the driving mode was simulated with the harmonic analysis. On the basis of the harmonic analysis, the influences of different error sources on the orthogonal coupling were studied. The results show that the perpendicularity error of side walls has a negligible effect on the orthogonal coupling. The Coriolis mass gravity center shift has a little influence on the orthogonal coupling, and the sensitivity of the orthogonal coupling coefficient is only  $0.0032\%/ \mu\text{m}$  even in the error sensitive direction. The machining error of the vibration structural support beam is the main factor resulting in the asymmetry of the structural stiffness and orthogonal coupling. The sensitivities of the orthogonal coupling coefficient to the width error and obliquity error of beam reach  $2.15\%/ \mu\text{m}$  (beam width error of  $\pm 0.1 \mu\text{m}$ ) and  $16\%/(\circ)$  (beam angle error of  $\pm 0.05^\circ$ ), respectively.

Key words: micro electromechanical system (MEMS); gyroscope; electrostatic drive; orthogonal coupling; finite element analysis (FEA)

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## Ib 型金刚石 NV 色心系综的制备及磁检测

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摘要: 弱磁探测在材料科学、基础物理和磁强计等众多领域都具有重要的研究意义。由于金刚石氮空位 (NV) 色心的弱磁探测兼具高灵敏度与高空间分辨的优点, 因此对利用 Ib 型金刚石 NV 色心系综进行磁检测的技术进行了研究。通过电子辐照并高温真空退火的方法制备了 Ib 型金刚石 NV 色心系综, 并对其光致发光光谱进行了测试与分析; 利用自主搭建的共聚焦系统成功检测了在不同微波功率作用下的 NV 色心系综电子自旋共振谱; 测试并分析了常温常压中不同磁场条件下的 NV 色心系综电子自旋共振谱。结果表明, 金刚石<100>晶轴方向的磁场使得 NV 色心系综基态的  $m_s=+1$  态与  $m_s=-1$  态的共振峰产生  $4\ 053\ \text{MHz/Gs}$  的能级分裂, 利用此金刚石 NV 色心系综可实现  $4\ 98\ \mu\text{T}$  的弱磁检测。

关键词: NV 色心; 电子辐照; 电子自旋共振; 弱磁检测; Ib 型金刚石

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Preparation of NV Center Ensembles in Type Ib

Diamonds and Magnetic Detection

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Abstract: The weak magnetic detection has important research significance in the fields of material science, basic physics, magnetometers and so on. Because the weak magnetic detection of nitrogen vacancy (NV) center in diamond has the advantages of high sensitivity and high spatial resolution, the magnetic detection technology utilizing NV center ensembles in the type Ib diamond was studied. The NV center ensembles in type Ib diamonds were prepared by the electron irradiation and high temperature annealing in vacuum, and their photoluminescence spectra were tested and analyzed. And the electron spin resonance spectra of the NV center ensembles were successfully detected under the different microwave powers by the self developed confocal system. Then, the electron spin resonance spectra of the NV center ensembles were tested and analyzed under different magnetic fields at the ambient temperature and pressure. The results show that the  $4\ 053\ \text{MHz/Gs}$  energy level splitting of the NV center ensemble formants at  $m_s=+1$  and  $m_s=-1$  was produced when applying magnetic fields in diamond <100> crystal axial direction. The  $4\ 98\ \mu\text{T}$  weak magnetic detection can be realized by using the NV center ensembles in diamond.

Key words: NV center; electron irradiation; electron spin resonance; weak magnetic detection; type Ib diamond

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## TiO<sub>2</sub> 纳米棒阵列的可控合成及其光电性能

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摘要: 采用简单的水热路线合成出 TiO<sub>2</sub> 纳米棒阵列, 作为染料敏化太阳电池 (DSSC) 光阳极, 并对其形貌、结构和光电特性进行表征。探讨了前驱体溶液总量、Ti 源加入量等对产物形貌以及 DSSC 性能的影响。研究表明: 增加前驱体溶液中 Ti 源的加入量将使纳米棒长度和直径同时增加, 最终导致形成“蒲公英”状产物, DSSC 性能有所提高, 同时暗电流也会随之增大; 增加前驱体溶液总量也会使纳米棒更长、更密, 但 DSSC 性能提高幅度不大, 暗态电流密度-电压 (J-V) 曲线几乎没有变化。研究将有助于人们更清楚地认识 TiO<sub>2</sub> 纳米棒阵列的生长动力学机制, 进而优化纳米棒阵列光电器件的性能。

关键词: 二氧化钛; 纳米棒; 阵列; 染料敏化太阳电池; 水热法

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Controllable Synthesis of the TiO<sub>2</sub> Nanorod Array and Its Photoelectric Properties

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Abstract: The TiO<sub>2</sub> nanorod array (NRA) was synthesized as the photoanode of the dye sensitized solar cell (DSSC) through the facile hydrothermal route, and the morphology, structure and photoelectric property of the TiO<sub>2</sub> nanorod array were characterized. The influences of the precursor solution total content and Ti source amount on the product morphology and DSSC performance were investigated. The study results show that the length and diameter of the nanorod increase simultaneously with the increase of Ti source amount in the precursor solution, leading to the formation of "dandelion" structure as well as the enhancement of DSSC performance and dark current. Besides, the nanorod can get longer and denser with the increase of the precursor solution total content, but the improvement of the DSSC performance is not obvious, and the dark current density-voltage (J-V) curve has little change. The study will be helpful for understanding the growth dynamics mechanism of the TiO<sub>2</sub> nanorod array and optimizing the properties of the nanorod array photoelectric device.

Key words: TiO<sub>2</sub>; nanorod; array; dye sensitized solar cell (DSSC); hydrothermal method

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无氧化剂条件下铜钴 CMP 去除速率的控制

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摘要: 利用不含氧化剂的碱性抛光液对铜和钴进行化学机械抛光, 深入分析了抛光液组分包括硅溶胶磨料、FA/O 螯合剂以及非离子表面活性剂对两种金属去除速率的影响规律及作用机理。实验结果表明, 铜和钴的去除速率随着磨料质量分数的增加而升高, 并且在磨料质量分数低于 5%时钴的去除速率为 20~30 nm/min, 而铜的去除速率几乎为零; 加入 FA/O 螯合剂可增强其与金属离子的络合, 从而加快铜和钴的去除速率; 非离子表面活性剂可以有效降低铜和钴的表面粗糙度。在抛光液各组分的协同作用下, 可以达到两种材料的低表面粗糙度和高去除速率选择性。

关键词: 阻挡层; 化学机械抛光(CMP); 钴; 去除速率; 碱性抛光液; 表面粗糙度

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Removal Rate Control for Copper and Cobalt

CMP Free of Oxidizing Agent

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Abstract: Copper and cobalt were polished using the alkaline slurry free of oxidizing agent, and the effects and mechanisms of slurry components including silica sol abrasive, FA/O chelating agent and non ionic surfactant on the removal rates of the two metals were analyzed. The experimental results show that the removal rates of copper and cobalt increase with the increase of the mass fraction of the abrasive. When the abrasive mass fraction is less than 5%, the removal rate of cobalt is 20-30 nm/min while the copper removal rate maintains almost zero. Adding FA/O chelating agent to enhance the complexation with metal ions, the removal rates of copper and cobalt are accelerated. The surface roughnesses of copper and cobalt are effectively reduced under the action of the non ionic surfactant. Under the synergistic effect of individual component of the slurry, low surface roughness and high removal rate selectivity of the two metals can be achieved.

Key words: barrier; chemical mechanical polishing (CMP); cobalt; removal rate; alkaline slurry; surface roughness

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化学气相沉积法可控制备石墨烯薄膜和单晶畴

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摘要: 采用化学气相沉积(CVD)法, 以铜箔为衬底, 以甲烷为碳源, 制备了石墨烯薄膜和单晶畴, 并利用扫描电子显微镜、光学显微镜、喇曼光谱仪、紫外-可见透射光谱仪等手段对石墨烯进行了系统表征。结果表明, 质量分数为 10%的稀硝酸对铜箔表面进行腐蚀处理 20 s 可以有效去除铜箔表面析出的杂质颗粒, 从而提高石墨烯的质量。在此基础上, 研究了氢气和甲烷体积流量比对石墨烯生长的影响, 当氢气和甲烷体积流量比从 0 : 1 变化到 5 : 1 时, 石墨烯薄膜从单层生长变化到多层生长。此外, 氢气和甲烷体积流量比也会显著影响晶畴的形状, 随着氢气和甲烷体积流量比的增加, 石墨烯晶畴从无规则形状逐渐变化到六边形。

关键词: 石墨烯; 单晶畴; 化学气相沉积(CVD); 铜箔; 体积流量比

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Controlled Preparation of the Graphene Film and Single Crystal

Domains by the Chemical Vapor Deposition Method

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Abstract:Using the chemical vapor deposition(CVD) method, the graphene film and single crystal domain were prepared with copper foils as the substrate and methane gas as the carbon source. Scanning electron microscope, optical microscope, Raman spectrometer and UV visible transmission spectrometer were applied to characterize the properties of graphene. The results show that the impurity particles of copper foils can be effectively removed after the corrosion treating for 20 s using HNO<sub>3</sub> with a mass fraction of 10%, and then the quality of graphene is improved. On this basis, the effects of the volume flow ratio between hydrogen and methane on the growth of graphene were also investigated. With the increase of the volume flow ratio between hydrogen and methane from 0 : 1 to 5 : 1, the growth of the graphene film changed from mono layer to multi layer. Furthermore, the shape of the single crystal domains was also influenced by the volume flow ratio between hydrogen and methane. With the increase of the volume flow ratio between hydrogen and methane, the graphene domains gradually changed from the irregular shape to the hexagon.

Key words:graphene; single crystal domain; chemical vapor deposition(CVD); copper foil; volume flow ratio

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