

## MEMS 智能传感器技术的新进展

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摘要: CMOS 和 MEMS 结合所产生的 MEMS 智能传感器技术已成为智能传感器发展的主流, 目前智能时代的开启已带动 MEMS 智能传感器技术进入快速发展阶段。综述了惯性、压力、温度和生化等典型的 MEMS 智能传感器, 展现了 MEMS 智能传感器的应用需求、技术特点、传感器新材料和新结构、电子学新架构、设计拓扑、关键技术突破和测试结果。同时也对 MEMS 智能传感器的工艺和封装技术的最新进展进行了陈述。从设计、工艺和封装等方面分析了当前 MEMS 智能传感器总的发展趋势, 并提取了主要技术创新亮点。

关键词: 智能传感; 微电子机械系统(MEMS); 惯性传感; 压力传感器; 温度传感器; 生化传感器

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New Progress of Smart Sensor Technology Based on MEMS

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Abstract: The micro  $\mu$  electromechanical system(MEMS) smart sensor technology generated by the combination of the CMOS and MEMS technologies has become the mainstream development of smart sensors. At present, the opening of the smart era has led the MEMS smart sensor technology to enter the rapid development stage. The typical MEMS smart sensors are summarized, such as inertia sensors, pressure sensors, temperature sensors, biochemistry sensors and so on. And the application requirements, technical features, new materials and structures of the sensors, new electronics architecture, design topology, key technological breakthroughs and test results of the MEMS smart sensors are presented. At the same time, the latest development of the MEMS smart sensor process and packaging technology are also introduced. The general development trend of the MEMS smart sensor is analyzed from the aspects of the design, process, packaging and so on, and the main technological innovation highlights are extracted.

Key words: smart sensor; micro  $\mu$  electromechanical system(MEMS); inertial sensor; pressure sensor; temperature sensor; biochemical sensor

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基于异靛蓝的供体-受体型共聚物

忆阻器的构建及性能

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摘要: 由于供体-受体型聚合物具有较强的诱捕和释放电荷的能力, 在忆阻器的研究方面具有很大的潜力。利用异靛蓝、丙烯二氧噻吩和噻吩合成了低带隙的供体-受体半导体聚合物(IPDT) (异靛蓝/噻吩/丙烯二氧噻吩的摩尔比率为 $x/1/1-x$ ), 构建了有机电子器件Al/IPDT/ITO, 发现器件具有较稳定的忆阻特性。 $x=0 \parallel 5$ 时器件的开、关电压分别为8和-7  $\parallel$  5 V, 高低电阻比达到102, 室温下的忍耐力循环测量超过2 000次。 $x=0 \parallel 25$ 时器件的开、关电压分别减小为2  $\parallel$  2/-1  $\parallel$  6 V, 最大电流下降了5个量级。 $x=0 \parallel 2$ 时器件的开、关电压分别为1  $\parallel$  9和-1  $\parallel$  1 V, 高低电阻比提高到103, 最大电流仍为纳安量级。结果表明供体单元的占比越高, 器件的开关电压越低, 且较低的电流更有利于降低功耗。发现器件的忆阻特性是由聚合物材料内部电子通道的形成与断裂引起的。

关键词: 忆阻器; 供体-受体; 有机聚合物; 异靛蓝; 电子通道

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Construction and Characteristics of the Donor  $\parallel$  Acceptor Type

Copolymer Memristor Based on Iso  $\parallel$  Indigo

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Abstract:The donor  $\parallel$  acceptor type polymer has a strong ability to trap and release charges, so it has great potential in the research of memristors. The donor  $\parallel$  acceptor type semiconductor polymer (IPDT) with low band gap was synthesized by iso  $\parallel$  indigo, thiophene and 3,3  $\parallel$  bis  $\parallel$  decyl  $\parallel$  3,4  $\parallel$  dihydro  $\parallel$  2 Hthieno [3,4  $\parallel$  b][1,4] dioxepine (ProDOT  $\parallel$  decyl2). The molar ratio of iso  $\parallel$  indigo/thiophene/ProDOT  $\parallel$  decyl2 was  $x/1/1-x$ . The Al/IPDT/ITO organic electronic device was constructed. It is found that the device has the stable memristive characteristics. When  $x=0 \parallel 5$ , the on/off voltages of the device are 8 V and -7  $\parallel$  5 V, the high/low resistance ratio reaches 102, and endurance cycles measurement is carried out over 2 000 times at room temperature. When  $x=0 \parallel 25$ , the on/off voltages decrease to 2  $\parallel$  2 and -1  $\parallel$  6 V, and the maximum current decreases by five orders of magnitude. When  $x=0 \parallel 2$ , the on/off voltages are 1  $\parallel$  9 and -1  $\parallel$  1 V, the high/low resistance ratio is up to 103, and the maximum current is still at the magnitude of nanoampere. The results show that the higher the ratio of donor units, the lower the on/off voltages of the device, and the lower current is more conducive to reduce power consumption. It is found that the memristive characteristics of the device is due to the formation and fracture of electronic channels inside polymer materials.

Key words:memristor; donor  $\parallel$  acceptor; organic semiconductor polymer; iso  $\parallel$  indigo; electronic channel

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高 k 金属栅 NMOSFET 器件阈值电压调控方法

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摘要: 实现对器件阈值电压的有效调控是高 k 金属栅(HKMG)技术面临的一项重要挑战。TiAl 薄膜作为 n 型金属氧化物半导体场效应晶体管 (NMOSFET) 的功函数层被广泛地应用于 HKMG 结构中以实现器件阈值电压的调控。实验采用射频(RF)-直流(DC) 磁控溅射的方式沉积 TiAl 薄膜, 通过优化直流功率、射频功率和反应压强工艺参数, 实现了对薄膜 Ti/Al 原子比率的调节, 提高了 Ti/Al 原子比率分布均匀度。基于实验结果, 采用后栅工艺流程制造 HKMG NMOSFET, 讨论不同的 Ti/Al 原子比率和 TiAl 层厚度对 NMOSFET 阈值电压的影响。Ti/Al 原子比率增大 10%, NMOSFET 的阈值电压增加 12 mV ± 6%; TiAl 层厚度增加 2 nm, NMOSFET 的阈值电压下降 19 mV ± 5%。这种方法已经被成功应用于 HKMG 器件的生产。

关键词: 高 k 金属栅(HKMG); 功函数层; 磁控溅射; Ti/Al 原子比率; 阈值电压; n 型金属氧化物半导体场效应晶体管 (NMOSFET)

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Control Method of the Threshold Voltage for High k

Metal Gate NMOSFET Devices

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Abstract: Effective control of device threshold voltages is a tough challenge for the high k metal gate (HKMG) technology. The TiAl film as a work function layer of n type metal oxide semiconductor field effect transistor (NMOSFET) was used in the HKMG structure to control the device threshold voltage. The TiAl film was prepared using the radio frequency(RF) direct current(DC) magnetron sputtering technique. By optimizing the DC power, RF power and reaction pressure, the adjustment of Ti/Al atomic ratio was achieved, and the uniformity of Ti/Al atomic ratio was improved. Based on the experimental results, the HKMG NMOSFET was fabricated by the gate last process. The impacts of different Ti/Al atomic ratios and TiAl layer thicknesses on the threshold voltage of the NMOSFET were discussed. With the Ti/Al atomic ratio increases by 10%, the threshold voltage of the NMOS increases by 12 mV ± 6%. With the increase of the TiAl layer thickness for 2 nm, the threshold voltage of the NMOSFET decreases by 19 mV ± 5%. The method has been successfully used in the production of the HKMG devices.

Key words: high k metal gate(HKMG); work function layer; magnetron sputtering; Ti/Al atomic ratio; threshold voltage; n type metal oxide semiconductor field effect transistor(NMOSFET)

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TiO<sub>2</sub>/TiN 复合纳米流体的光吸收与光热转换性能

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摘要: 利用纳米流体作为工作介质来实现太阳能光热转换是太阳能利用的最简单方式。将二氧化钛(TiO<sub>2</sub>)纳米颗粒和氮化钛(TiN)纳米颗粒均匀分散在水中形成 TiO<sub>2</sub>/TiN 复合物纳米流体, 进而研究复合物纳米流体的光吸收与光热转换性能。利用 X 射线衍射仪 (XRD)、透射电子显微镜 (TEM) 和 BET 比表面积测试等技术对 TiO<sub>2</sub> 和 TiN 纳米颗粒的晶体结构、微观形貌以及比表面积等进行了表征。利用紫外/可见/近红外吸收光谱仪和自搭建光热转换装置对纳米流体的光吸收与光热转换性能进行了测试。研究表明, TiO<sub>2</sub> 纳米流体具有较弱的光吸收与光热转换性能, 但添加 TiN 纳米颗粒后, TiO<sub>2</sub>/TiN 复合物纳米流体在可见光与近红外区域的吸收显著增强; 同时, 复合物纳米流体的光热转换性能也得到显著提高, 其升温幅度约为 33 ~ 35 °C, 远高于单一 TiO<sub>2</sub> 纳米流体的升温幅度 (约 25 ~ 32 °C)。

关键词: TiO<sub>2</sub>; TiN; 纳米流体; 光吸收; 光热转换

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Optical Absorption and Photo // Thermal Conversion Properties of  
TiO<sub>2</sub>/TiN Composite Nanofluids

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Abstract:By using the nanofluids as the working medium, solar photo // thermal conversion is the simplest way to utilize the solar energy. The titanium dioxide (TiO<sub>2</sub>) and titanium nitride (TiN) nanoparticles were dispersed uniformly in water to form TiO<sub>2</sub>/TiN composite nanofluids, and then the optical absorption and photo // thermal conversion properties of the composite nanofluids were studied. The crystal structures, micro morphologies and specific surface areas of the TiO<sub>2</sub> and TiN nanoparticles were characterized by X // ray diffraction(XRD), transmission electron microscopy (TEM) and BET specific surface area test. The optical absorption and photo // thermal conversion properties of the nanofluids were tested by ultraviolet/visible/near infrared absorption spectrometer and self // made photo // thermal conversion device. The measured results show that the TiO<sub>2</sub> nanofluids have a weaker optical absorption and photo // thermal conversion properties. However, the optical absorption of the TiO<sub>2</sub>/TiN composite nanofluids is significantly enhanced in visible and near infrared regions due to the introduction of TiN nanoparticles. Meanwhile, the photo // thermal conversion property of the composite nanofluids is also effectively improved, and the temperature increment is about 33 ~ 35 °C, which is much higher than that of the single TiO<sub>2</sub> nanofluids (about 25 ~ 32 °C).

Key words:TiO<sub>2</sub>; TiN; nanofluids; optical absorption; photo // thermal conversion

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## Design and Fabrication of a MEMS Heater with the Improved Double $\Pi$ Spiral Structure

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**Abstract:** A micro  $\Pi$  electromechanical system (MEMS) heater with the improved double  $\Pi$  spiral structure was designed and fabricated for a heating unit and sensing unit in the high temperature gas sensor. The MEMS heater utilized silicon as the substrate,  $\text{SiO}_2/\text{Si}_3\text{N}_4$  nano thin film as the heat insulating layer, and Pt/Ti layer as the heating unit and sensing unit. Low power consumption and temperature uniformity are realized by using the multiplied double  $\Pi$  spiral structure, and the width of the spiral structure is gradually narrowed down from inner to outer. The simulation optimization of the structure was performed by Comsol. The device was fabricated by standard MEMS manufacturing technology. Then the electro  $\Pi$  thermo properties of the device at different voltages were tested by an infra  $\Pi$  red microscopic thermometer. The device has the characteristics of low power consumption, quick response, high reliability, high temperature coefficient of resistance (TCR) and so on. The power consumption of the device is only 120 mW when the device is heated up to  $687 \pm 7^\circ\text{C}$ . The temperature increase (23-600  $^\circ\text{C}$ ) response time and temperature decrease (600-23  $^\circ\text{C}$ ) response time of the device are 1 ms and  $2 \pm 5$  ms, respectively. The heater can work at  $687 \pm 7^\circ\text{C}$  for at least 5 h to maintain the performances.

**Key words:** micro  $\Pi$  electromechanical system(MEMS) heater; micro  $\Pi$  and nano  $\Pi$  fabrication; gas sensor; thin film; double  $\Pi$  spiral structure; Pt

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一种改进的双螺旋结构 MEMS

加热器的设计和制造

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**摘要:**设计制造了一种改进的双螺旋结构 MEMS 加热器, 可用于高温气体传感器作为加热和传感单元。该 MEMS 加热器以 Si 为基底,  $\text{SiO}_2/\text{Si}_3\text{N}_4$  纳米薄膜作为绝热层, Pt/Ti 金属薄膜作为加热单元和传感单元。通过应用并联的线宽由内向外逐渐减小的双螺旋结构, 实现温度的均匀性和低功耗。用 Comsol 进行仿真优化结构, 通过 MEMS 工艺加工制造出器件并进行了测试, 用红外显微测温仪测试器件在不同电压下的电热特性。该器件表现出低功耗、响应迅速、高可靠性和高的温度电阻系数 (TCR) 等特点。器件加热到  $687 \pm 7^\circ\text{C}$ , 功耗仅 120 mW。器件的升温 (23~600  $^\circ\text{C}$ ) 响应时间和降温 (600~23  $^\circ\text{C}$ ) 响应时间分别为 1 ms 和  $2 \pm 5$  ms。该加热器可以在  $687 \pm 7^\circ\text{C}$  的高温下工作至少 5 h 而保持性能不变。

**关键词:**微电子机械系统 (MEMS) 加热器; 微纳制造; 气体传感器; 薄膜; 双螺旋结构; 铂 (Pt)

掺铒光纤谐振腔陀螺的谐振腔设计

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摘要: 光纤谐振腔作为谐振式光学陀螺的核心传感器件, 其性能直接决定了谐振式光学陀螺的灵敏度。目前使用的光纤谐振腔存在着品质因数偏低的问题, 极大地限制了谐振式光学陀螺极限灵敏度的提升。将掺铒光纤引入到光纤谐振腔中并外加高稳定性的泵浦激光器形成掺铒光纤谐振腔, 从而有效提升了谐振腔的品质因数。通过对激光功率、掺铒光纤长度等参数的实验探索, 确定了最佳的掺铒光纤谐振腔的设计参数, 实现了应用于谐振式光学陀螺品质因数为  $1 \times 10^9$  的掺铒光纤谐振腔。搭建了基于掺铒光纤腔的谐振式光学陀螺测试系统, 经实验测试该系统的零偏稳定性为  $0.0775^\circ/\text{s}$ , 验证了掺铒光纤腔在陀螺系统中的应用, 为新型角速度测量技术提供了新的研究思路和发展方向。

关键词: 谐振式光学陀螺; 掺铒光纤; 谐振腔; 品质因数; 零偏稳定性

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Design of the Resonant Cavity in Erbium Doped

Fiber Resonator Gyroscopes

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Abstract: The fiber resonator is the core sensing device in the resonant optical gyroscope, its performances are crucial to the sensitivity of the resonant optical gyroscope. The quality factor of the current fiber resonator is low, which greatly limits the improvement of the extreme sensitivity for the resonant optical gyroscope. The erbium doped fiber was introduced into the fiber resonator and a pump laser with high stability was subsequently added to form an erbium doped fiber resonator, and the quality factor of the resonator was effectively improved. The optimum design parameters of the erbium doped fiber resonator were determined by the experimental exploration of the laser power and length of erbium doped fiber. The erbium doped fiber resonator with the quality factor of  $1 \times 10^9$  used for the resonant optical gyroscope was achieved. The test system of the resonant optical gyroscope based on the erbium doped fiber resonator was built. The experimental test results show that the zero bias stability of the system is  $0.0775^\circ/\text{s}$ , verifying the application of the erbium doped fiber resonator in the gyroscope system and providing a new research idea and development direction for the new angular velocity measurement technology.

Key words: resonant optical gyroscope; erbium doped fiber; resonator; quality factor; zero bias stability

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一种钴基磷酸根电化学传感器的研制

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摘要: 磷酸根离子是一种对作物生长非常重要的土壤速效养分, 但由于盲目过量施肥, 使其成为导致水体富营养化的最主要因素。研究并开发了一种低成本的钴基磷酸根离子电化学传感器。在一定条件下, 采用恒电流沉积法在钴基电极上电沉积纳米钴敏感薄膜, 该固态离子选择电极对磷酸根离子浓度的线性响应范围为  $10^{-5} \sim 10^{-1}$  mol/L, 线性相关系数为 0.994, 斜率为 -50 mV/decade, 检测下限为  $10^{-6}$  mol/L, 电极具有较短的响应时间, 在 60 s 内可以达到稳定状态, 该电极的研究与开发对土壤速效磷和环境水质中磷酸根的检测研究具有一定的意义。

关键词: 电化学传感器; 磷酸根离子; 钴; 电沉积; 固态离子选择电极

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Development of a Cobalt Based Phosphate Electrochemical Sensor

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Abstract: Phosphate ion is one of the most important soil available nutrients for crop growth, however, it becomes the most essential factor that leads to the eutrophication because of the blind and excessive fertilization. A low cost cobalt based phosphate ion electrochemical sensor was studied and developed. The nano cobalt sensitive membrane was prepared on the cobalt based electrode by the galvanostatic deposition method under certain conditions. The solid state ion selective electrode exhibits a linear response to phosphates in the concentration range from  $10^{-5}$  to  $10^{-1}$  mol/L with a linear correlation coefficient of 0.994, a slope of -50 mV/decade and a low detection limit of  $10^{-6}$  mol/L. Furthermore, the electrode has a shorter response time and can reach steady state within 60 s. The research and development of the ion selective electrode will have a positive significance for the detection of phosphate in soil available phosphorus and environmental water quality.

Key words: electrochemical sensor; phosphate ion; cobalt; electrodeposition; solid state ion selective electrode

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基于 T 矩阵模型的光纤芯片的制备及其细胞驱动

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摘要: 基于 T 矩阵模型, 推导出单模光纤光镊对细胞的驱动力公式。以 COMSOL Multiphysics 5.0 为仿真软件, 首先模拟出单模光纤的磁场模和电场模分布, 得出在纤芯处场强最大, 激光聚焦于此, 然后又模拟出同一功率和波长条件下的光纤光镊对不同直径微粒的驱动作用, 模拟结果表明不同直径的微粒沿着光轴移动的距离不等。提出了用于细胞驱动的光纤芯片的制作方法, 并在波长为 980 nm、功率为 300 mW 激光条件下对聚苯乙烯微球和酵母菌细胞的混合液进行了驱动实验。该实验结果表明, 在同种条件下, 聚焦激光可以通过单模光纤驱动不同直径的细胞沿光轴方向移动, 且移动距离不相等, 为下一步细胞分选提供了理论和实验基础。

关键词: 光镊; 细胞; 驱动力; 光纤芯片; T 矩阵

中图分类号: TN2 文献标识码: A 文章编号: 1671-4776(2019)01-0045-06

Fabrication of the Optical Fiber Chip Based on T Matrix

Model for Driving Cells

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Abstract: Based on the T matrix model, the driving force formula of single mode optical fiber tweezers for cells was derived. Using COMSOL Multiphysics 5.0 as the simulation software, the magnetic field mode distribution and electric field mode distribution of the single mode optical fiber were simulated firstly. The results show that the field intensity is the highest at the fiber core, so the laser is focused on it. Then the driving effect of fiber optical tweezers on particles with different diameters under the same power and wavelength was simulated. The result shows that the moving distances of microparticles with different diameters along the optical axis are not equal. A method of processing fiber chips for driving cells was proposed, and the drive experiment of the mixed solution of polystyrene microspheres and yeast cells was carried out under the laser condition of 980 nm wavelength and 300 mW power. The experimental results show that under the same condition, the focused laser can drive the cells with different diameters to move along the optical axis direction through the single mode fiber, and the moving distance was not equal, providing the theoretical and experimental basis for the next cell sorting.

Key words: optical tweezer; cell; driving force; optical fiber chip; T matrix

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基于磁弹性生物传感器检测癌胚抗原

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摘要:基于磁致伸缩材料将巯基十一烷酸自组装于磁弹性芯片,经 N 卩羟基丁二酰亚胺(NHS)和 1 卩乙基卩(3 卩二甲基氨基丙基)碳二亚胺盐酸盐(EDC)活化后固载癌胚抗原抗体(Anti 卩 CEA),设计构建了一种新型且低成本的磁弹性生物传感器,基于抗原-抗体特异性识别以及传感器质量增加其共振频率降低的机理,实现对癌胚抗原(CEA)的检测。采用荧光显微镜对异硫氰酸荧光素标记的癌胚抗原抗体(FITC/Anti 卩 CEA)功能化浓度进行了优化,采用原子力显微镜(AFM)和扫描电子显微镜(SEM)对裸金层、自组装膜(SAM)、Anti 卩 CEA 负载以及 CEA 检测进行了表征。实验结果表明, Anti 卩 CEA 最佳修饰质量浓度为 50  $\mu\text{g}/\text{mL}$ , CEA 线性响应范围为 200~1 000 ng/mL,检测下限为 200 ng/mL。该磁弹性生物传感器有望实现高灵敏快速癌症标志物 CEA 的检测。

关键词:磁致伸缩材料;自组装;癌胚抗原(CEA);共振频率;磁弹性生物传感器

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Detection of Carcinoembryonic Antigen Based on

Magnetoelastic Biosensors

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Abstract:The thiol undecanoic acid was self 卩 assembled on the magnetoelastic chip based on magnetostrictive materials, and activated with the EDC and NHS to immobilize the Anti 卩 CEA, and then a novel and low 卩 cost magnetoelastic biosensor was designed. Based on the antigen 卩 antibody specific recognition and the mechanism of the resonance frequency reduction with the increase of the sensor quality, the carcinoembryonic antigen(CEA) was detected. The functional concentration of the FITC/Anti 卩 CEA was optimized by the fluorescence microscope. The atomic force microscope (AFM) and scanning electron microscope (SEM) were used to characterize the bare gold layer, self 卩 assembled film(SAM), Anti 卩 CEA immobilization and CEA detection. The experimental results show that the optimal modification mass concentration of the Anti 卩 CEA is 50  $\mu\text{g}/\text{mL}$ , the linear response range of the CEA is 200-1 000 ng/mL, and the low detection limit is 200 ng/mL. The magnetoelastic biosensor will be applied in highly sensitive and rapid CEA detection.

Key words:magnetostrictive material; self 卩 assembly; carcinoembryonic antigen (CEA); resonance frequency; magnetoelastic biosensor

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基于针尖阵列的柔性干电极制备与测试

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摘要: 针对目前 Ag/AgCl 湿电极存在导电膏干涸而导致的信号质量变差、电极-皮肤接触阻抗变大等问题, 提出一种可测量生物电信号的柔性干电极的制备方法。结合深反应离子刻蚀 (DRIE) 和湿法腐蚀工艺制备出硅针尖模具, 后经聚对二甲苯薄膜的保形淀积完成聚二甲基硅氧烷 (PDMS) 两次翻膜工艺, 并有效解决了 PDMS 与金属种子层之间的黏附性问题。使用 COMSOL 软件对干电极和湿电极进行电场仿真, 结果显示干电极能显著提高生物电信号提取的有效性和稳定性。通过对干电极与湿电极进行电极-皮肤接触阻抗的对比测试, 表明湿电极随着导电膏干涸而导致接触阻抗逐渐变大并超过干电极, 相反干电极的接触阻抗则较为稳定。该方法制备的柔性干电极具有工艺简单、成本较低、适于批量化生产、材料生物兼容性好、接触阻抗稳定等优点。

关键词: 针尖阵列; 柔性干电极; 聚对二甲苯薄膜; 聚二甲基硅氧烷 (PDMS); 电场仿真; 电极-皮肤接触阻抗; 生物电信号

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Preparation and Test of the Flexible Dry Electrode

Based on Tip Arrays

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Abstract: For resolving the problems of poor signal quality and large electrode // skin contact impedance caused by the dryness of conductive paste on Ag/AgCl wet electrode, the preparation method of the flexible dry electrode for measuring bio // electrical signals was proposed. The silicon tip mould was fabricated by deep reactive ion etching (DRIE) process and wet etching process. With parylene film conformal deposition, the double // transfer pattern process of the polydimethylsiloxane (PDMS) was accomplished, and the adhesion problem between the PDMS and metal seed layer was solved effectively. The electric field simulations of the dry electrode and wet electrode were carried out by the COMSOL software. The results show that the dry electrode can significantly enhance the validity and stability of bio // electrical signal extraction. The electrode // skin contact impedances of the dry electrode and wet electrode were compared and tested. It shows that with the conductive paste drying, the contact impedance of the wet electrode gradually becomes larger and exceeds the contact impedance of the dry electrode. On the contrary, the contact impedance of the dry electrode is relatively stable. The proposed flexible dry electrode prepared with the method has the advantages of simple process, low cost, mass production, good material bio // compatibility and stable contact impedance.

Key words: tip array; flexible dry electrode; parylene film; polydimethylsiloxane (PDMS); electric field simulation; electrode // skin contact impedance; bio // electrical signal

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电流体动力学近场直写工艺参数对微图案的影响

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摘要: 以聚氧化乙烯(PEO)为直写溶液, 光泽柔性绝缘相纸作为基板材料, 采用自主研发的电流体动力学近场直写(ENDW)设备直写微图案。研究了工作电压、直写高度和直写溶液的质量分数等参数对PEO溶液的直写微图案宽度的影响。结果表明在使用质量分数3%的PEO溶液在进行直写时, 喷嘴与基底之间的工作电压从1 || 1 kV增大到2 || 6 kV, PEO微图案的平均宽度从35 || 61  $\mu\text{m}$ 下降到23 || 3  $\mu\text{m}$ , 并且图案宽度的工艺误差从8 || 24  $\mu\text{m}$ 下降到2 || 21  $\mu\text{m}$ 。随着工作电压的增大, 喷嘴处的射流形态变化依次为: 液滴状、弯液面、稳定射流、多股射流。同时研究发现, 通过降低直写高度和增加PEO溶液的质量分数, 能进一步减小微图案的宽度, 并且能够提高微图案宽度的均匀性。

关键词: 电流体动力学; 近场直写; 微图案; 聚氧化乙烯(PEO); 柔性绝缘基板

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Effects of the Electrohydrodynamic Near || Field Direct || Writing  
Process Parameters on Micro Patterns

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Abstract: With the polyethylene oxide (PEO) as the direct || writing solution and glossy flexible insulating photopaper as the substrate material, the micro patterns were directly written by the self || developed electrohydrodynamic near || field direct || writing (ENDW) setup. The effects of the working voltage, direct || writing height and mass fraction of the direct || writing solution on the width of direct || writing micro patterns with the PEO solution were studied. The results show that using the PEO direct || writing solution with a mass fraction of 3%, the working voltage between the nozzle and substrate increases from 1 || 1 kV to 2 || 6 kV, the average width of the PEO micro patterns decreases from 35 || 61  $\mu\text{m}$  to 23 || 3  $\mu\text{m}$ , and the fabrication error of the micro pattern width decreases from 8 || 24  $\mu\text{m}$  to 2 || 21  $\mu\text{m}$ . With the increase of the working voltage, the jetting behavior of the nozzle changes in order of the droplet, curved surface, stable jet and multiple jets. At the same time, the study result shows that by reducing the direct || writing height and increasing the mass fraction of the PEO solution, the width of the micro patterns can be further reduced, and the uniformity of the micro pattern width is improved.

Key words: electrohydrodynamic; near || field direct writing; micro pattern; polyethylene oxide(PEO); flexible insulating substrate

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基于 SIFT 图像拼接算法的标准样板测量技术

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摘要: 为了在使用高倍物镜测量标准样板时获得高分辨率的样本整体区域信息, 提出了一种基于尺度不变特征变换 (SIFT) 图像拼接算法的标准样板测量技术。首先通过高倍物镜获取局部三维结构, 将其转化为二维灰度图像; 然后采用 SIFT 和 RANSAC 算法得到准确的特征点; 最后采用加权平均融合算法得到完整图像, 重构整体样板三维结构, 并利用 ISO 5436-1 : 2000 对标准样板台阶高度进行评价。实验对 100 和 400 nm 两种高度的标准样板进行了测量和拼接, 并对拼接后的台阶高度进行评价, 测量均值分别为  $100 \pm 3$  和  $398 \pm 9$  nm, 实验表明该技术能准确还原标准样板中台阶的高度, 有效扩大了标准样板形貌重构的范围。

关键词: 微纳米测量; 图像拼接; 标准样板; 台阶高度标准; 形貌重构

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Measurement Technology of the Standard Template Based on  
the SIFT Image Stitching Algorithm

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Abstract: In order to obtain the overall region information of the high resolution sample by using high magnification objective lens to measure the standard template, the standard template measurement technology based on the scale invariant feature transform (SIFT) image stitching algorithm was presented. Firstly, the local three dimensional structure was obtained by the high magnification objective and was transformed into the two dimensional gray image. Then the SIFT and RANSAC algorithm were used to obtain accurate feature points. Finally, the weighted average fusion algorithm was used to obtain the complete image, and the overall template three dimensional structure was reconstructed. The step height of the standard template was evaluated using the ISO 5436-1 : 2000. The standard templates with the step heights of 100 nm and 400 nm were measured and stitched, and the step heights after stitching were evaluated. The average values were  $100 \pm 3$  nm and  $398 \pm 9$  nm, respectively. The experiments show that the technology can accurately restore the step height in the standard template, and has effectively expanded the scope of standard template morphology reconstruction.

Key words: micro nano measurement; image stitching; standard template; step height standard; morphology reconstruction

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用于线虫药物筛选的微流控梯度芯片和自动化平台

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**摘要:**作为一种在微米尺度操作流体的技术, 微流控芯片具有反应体系小、通量高、自动化且操作灵活等优势, 被越来越多地应用于细胞和微米尺度生物的研究中。秀丽隐杆线虫作为一种重要的模式生物被广泛地用于神经生物学、衰老及发育和药物筛选等研究中。提出了一种用于研究线虫和环境毒素相互作用的微流控自动化平台, 该平台集成了基于微振荡原理的快速梯度形成的微流控芯片、自动化控制系统及基于 OpenCV 的线虫长度及摆动频率估计的自动化图像分析软件。通过染料和荧光实验验证了基于振荡原理的快速梯度形成芯片, 该芯片可以在 7 min 内形成线性浓度梯度, 并通过该芯片和平台验证了线性浓度梯度的双氧水对秀丽隐杆线虫活性的影响。

**关键词:** 微流控芯片; 秀丽隐杆线虫; 自动化平台; 药物筛选; 环境毒素

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Microfluidic Gradient Chip and Automation Platform for

Drug Screening of *C. elegans*

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**Abstract:**As a technology for operating fluids on the micrometer scale, microfluidic chips have the advantages of small reaction system, high throughput, automation and flexible operation, and are increasingly used in the research of cells and microscale organisms. As an important model organism, the *C. elegans* are widely used in the research of neurobiology, aging, development and drug screening. The microfluidic automation platform for the study of the interaction between *C. elegans* and environmental toxins was presented. The platform integrated the fast gradient forming microfluidic chip based on the micro oscillation principle, automatic control system and OpenCV based software for automatic image analysis of *C. elegans* length and wobble frequency estimation. The fast gradient forming chip based on the oscillation principle was verified by dye and fluorescence experiments. The chip can form a linear concentration gradient within 7 min. The effect of the linear concentration gradient hydrogen peroxide on the activity of *C. elegans* was verified by the chip and platform.

**Key words:** microfluidic chip; *C. elegans*; automation platform; drug screening; environmental toxin

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