

一种 MTM 反熔丝器件的击穿特性

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摘要: 制备了一种基于高介电常数材料氧化铪(HfO<sub>2</sub>)薄膜作为核心绝缘介质层的金属-金属(MTM)反熔丝单元结构。基于此结构, 使用钛(Ti)和氮化钛(TiN)分别作为 MTM 反熔丝结构中的过渡层和阻挡层, 得到了致密、均匀、无针孔缺陷以及上下电极接触良好的反熔丝单元。讨论了反熔丝单元的击穿过程及击穿现象, 并重点研究了该结构的击穿特性和时变击穿(TDDB)特性。研究表明, 此结构不仅具有良好的工艺一致性和较低的击穿电压(4~3 V), 并且工作电压(1~8 V)下的时变击穿时间超过 13 年。其结构可以进一步应用于反熔丝型现场可编程逻辑阵列(FPGA)的互连结构。

关键词: 反熔丝; 金属-金属(MTM); 击穿电压; 时变击穿(TDDB); E 模型; 可靠性

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Breakdown Characteristics of an MTM Antifuse Device

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Abstract:A metal to metal (MTM) antifuse unit structure was prepared with the high dielectric constant material hafnium oxide (HfO<sub>2</sub>) film as the core insulation dielectric layer. Based on this structure, titanium (Ti) and titanium nitride (TiN) were used as the transition layer and barrier layer of the MTM antifuse structure, respectively, and the dense and uniform antifuse unit without pinhole defects and with a good contact between the upper and lower electrodes was obtained. The breakdown process and breakdown phenomenon of the antifuse unit were discussed, and the breakdown characteristic and time dependent dielectric breakdown (TDDB) characteristic of the structure were mainly studied. The results show that the structure has good process consistency and low breakdown voltage (4~3 V), and its TDDB time is more than 13 years at the working voltage of 1~8 V. The structure can be further applied in the interconnect structure of the antifuse field programmable gate array (FPGA).

Key words:antifuse; metal to metal (MTM); breakdown voltage; time dependent dielectric breakdown (TDDB); reliability

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基于忆阻振荡电路元胞耦合的图灵斑图

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摘要: 采用有源忆阻器构建了三阶忆阻振荡电路单元。将该忆阻振荡电路单元作为构建忆阻非线性网络的元胞, 通过与周围邻近元胞的耦合, 实现了具有反应扩散特性的非线性忆阻电路网络。通过 MATLAB 实验仿真观察到了该网络产生的图灵斑图。进一步研究了忆阻元胞参数 ( $\alpha$ ,  $\beta$ ) 和扩散系数 ( $D_{11}, D_{12}, D_{21}, D_{22}$ ) 对图灵斑图形成的影响。通过对不同参数的仿真, 发现忆阻元胞参数影响斑图中斑点密度, 而扩散系数影响斑图的形状。研究结果可为忆阻器实现在图像处理 and 模式识别方面的应用提供重要的理论依据。

关键词: 细胞非线性网络(CNN); 忆阻器; 反应扩散; 图灵斑图; 元胞耦合

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Turing Patterns Based on the Cell Coupling of the

Memristive Oscillating Circuit

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Abstract: A three order memristive oscillating circuit unit was built by active memristors. The memristive oscillating circuit was used as a basic unit to establish the memristive nonlinear network cell. By coupling the memristive oscillating circuit with the neighbor cells, the nonlinear memristive circuit network with the reaction diffusion characteristic was achieved. Through the MATLAB experiment simulation, the formation of Turing patterns generated by the network was observed. The effects of the memristive cell parameters ( $\alpha, \beta$ ) and diffusion coefficients ( $D_{11}, D_{12}, D_{21}, D_{22}$ ) on the formation of Turing patterns were further studied. By the simulation of the different parameters, it is found that the memristive cell parameters affect the density of the spots of Turing patterns, and the diffusion coefficients affect the shape of the patterns. The research results provide the important theoretical foundation for the applications of memristors in the image processing and pattern recognition.

Key words: cellular nonlinear network(CNN); memristor; reaction diffusion; Turing pattern; cell coupling

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键合 SOI 材料应力的控制技术

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摘要: 在基于绝缘体上硅(SOI)材料的 IC 器件及 MEMS 器件研发过程中, 薄膜应力引起的晶圆变形、膜层脱落等工艺问题, 制约了其研发进度和器件性能。对键合 SOI 材料整体残余应力展开研究, 推出埋氧层、背面氧化层、衬底厚度与 SOI 整体残余应力的关系, 并采用翘曲度值表征由残余应力引起的 SOI 形变的大小, 弯曲度的正负表征 SOI 形变的方向。针对 IC 和 MEMS 产品在开发过程中因残余应力过大而引起的光刻无法吸片、牺牲层释放不干净等问题, 通过工艺优化, 制备出与残余应力方向相反、应力大小适中的 SOI 片, 从而抵消了部分残余应力, 翘曲度由 200  $\mu\text{m}$  以上下降到 100  $\mu\text{m}$  以内, 有效解决了工艺异常问题。

关键词: 绝缘体上硅(SOI); 微电子机械系统 (MEMS); 翘曲度; 张应力; 压应力

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Stress Control Technology of Bonded SOI Materials

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Abstract: In the process of research and development for IC and MEMS devices based on silicon on insulator(SOI) materials, the technology problems caused by the film stress, such as the wafer deformation, film desquamation and so on, restrict the development progress and performances of these devices. The overall residual stress of the bonded SOI material was studied, the relationships between the residual stress and the buried oxide layer, oxide layer on the back and substrate thickness were deduced. The size of the SOI deformation caused by the residual stress was characterized by the warp values, and the direction of the SOI deformation was characterized by the positive and negative of bow. To resolve the problems caused by the large residual stress during the development of IC and MEMS products, including that the wafer can not be sucked in lithography process and the sacrifice layer can not be released completely, through the process optimization, the SOI materials with the opposite direction to the residual stress and appropriate stress were prepared, thus offsetting some of the residual stress. The warp value decreases from more than 200  $\mu\text{m}$  to within 100  $\mu\text{m}$ . The abnormal process problems were effectively solved.

Key words: silicon on insulator(SOI); micro electromechanical system (MEMS); warp; tensile stress; compressive stress

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微纳米复合结构强化微通道内沸腾  
换热的研究进展

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摘要: 针对具有微纳米复合结构的微通道, 对流动沸腾换热的沸腾起始点、换热系数、临界热流密度、流动不稳定性等问题的最新研究进展进行了综述, 总结出近些年实验研究中所采用的实验方法, 包括在微通道表面制作多孔型涂层、制作不同润湿性表面的微通道以及改变微通道的形状尺寸, 指出了相关研究中有待解决的问题: 保证微通道表面的涂层结构在实验前后保持稳定, 避免微通道表面润湿性实验前后发生改变, 设计制作出强化沸腾换热效果更好的具有新型结构的微通道。并对今后的发展趋势进行了展望。

关键词: 微通道; 散热器; 微纳米复合结构; 流动沸腾; 强化传热

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Research Progress on the Flow Boiling Heat Transfer Enhancement by  
Using Micro/Nano Compound Structures in Microchannels

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Abstract:According to the microchannels with micro/nano compound structures, the latest research progress of the flow boiling heat transfer are reviewed, focusing on the four key problems of the boiling incipience, heat transfer coefficient, critical heat flux and flow instability. The experimental methods used for the experiment and research in recent years are concluded, including the preparation of the porous coating on the surface of the microchannels, fabrication of the microchannels with different wettability surfaces, variation of the shape and size of the microchannels. The open problems in related researches are pointed out, i e. ensuring the stability of the coating structure on the microchannel surface before and after the experiment, avoiding the wettability change of the microchannel surface before and after the experiment, designing and fabricating the microchannel with a new structure and good boiling heat transfer enhancement effect. And the development trend in the future is prospected.

Key words:microchannel; radiator; micro/nano compound structure; flow boiling; heat transfer enhancement

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## 高 Q 平面集成光波导谐振腔

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摘要: 提出了一种高品质因数的氧化硅平面集成光波导谐振腔的设计与加工方案。利用 Matlab 与 BeamPROP 软件对回音壁模式 (WGM) 谐振腔结构模型进行了仿真分析, 深入讨论了耦合状态、腔长与谐振腔品质因数的关系。设计了直径 6 cm 的环形光波导谐振腔, 直波导与环形腔的耦合率为 3.3%。整个谐振腔耦合结构被设计为欠耦合状态来优化其品质因数。在此基础上, 在硅衬底上采用等离子体增强化学气相沉积 (PECVD) 技术和紫外光刻技术制作出二氧化硅光波导谐振腔芯片, 芯片尺寸为 7 cm×7 cm。利用一个波长为 1 550 nm 可调谐激光器对谐振腔的光谱进行了测试, 测试结果表明所加工出的氧化硅光波导谐振腔的品质因数高达  $4.3 \times 10^7$ 。

关键词: 回音壁模式 (WGM); 谐振腔; 硅基二氧化硅; 品质因数; 光波导

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### A High Q Planar Integrated Optical Waveguide Resonator

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Abstract: A design and processing scheme of the silica planar integrated optical waveguide resonator with high quality factor was presented. The structure model of the whispering gallery mode (WGM) resonator was simulated and analyzed by the Matlab and BeamPROP softwares. The relationships between the coupling state, cavity length and quality factor of the resonator were further discussed. The ring optical waveguide resonator with the diameter of 6 cm was designed. The coupling efficiency between the straight waveguide and ring cavity is 3.3%. The resonator coupling structure was designed in under coupling state to optimize the quality factor. And on this basis, using the plasma enhanced chemical vapor deposition (PECVD) technology and UV lithography technology, the silica optical waveguide resonator chip with the size of 7 cm×7 cm was fabricated on the silicon substrate. The spectrum of the resonator was tested by a tunable laser with the wavelength of 1 550 nm. The test results show that the quality factor of the fabricated silica optical waveguide resonator is up to  $4.3 \times 10^7$ .

Key words: whispering gallery mode (WGM); resonator; silicon based silica; quality factor; optical waveguide

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基于新型谐振柱的高频波导滤波器的设计

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摘要: 为了减小加工误差对高频滤波器性能的影响, 设计并加工了一款基于新型谐振柱的高频波导滤波器。首先设计了一个两腔波导滤波器, 然后通过给腔内的方形脊两侧加载梯形凸台完成了滤波器的设计。运用 Ansoft HFSS 软件对滤波器进行了模型仿真和参数优化。仿真优化结果显示, 滤波器中心频率为 104 GHz, 带宽约为 3 GHz, 插入损耗小于 0.1 dB, 回波损耗大于 25 dB, 且梯形凸台的加载有助于增强腔间耦合, 将加工误差影响减小为原来的一半。最后用微电子机械系统 (MEMS) 工艺完成了滤波器的加工并对其进行了测试, 测试结果与仿真结果大致吻合, 为高频滤波器的设计和加工提供了参考。

关键词: 谐振柱; 波导滤波器; 加工误差; 梯形凸台; HFSS; 微电子机械系统 (MEMS)

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Design of a High Frequency Waveguide Filter Based on  
a New Type of Resonant Column

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Abstract: In order to reduce the influence of the machining error on the performances of the high frequency filter, a high frequency waveguide filter based on a new type of resonant column was designed and fabricated. Firstly, a double cavity waveguide filter was designed, and then the design of the filter was completed by loading the trapezoidal boss on both sides of the square ridge in the cavity. The model simulation and parameter optimization of the filter were carried out by the Ansoft HFSS software. The results show that the center frequency of the filter is 104 GHz, the bandwidth is about 3 GHz, the insertion loss is less than 0.1 dB, and the return loss is greater than 25 dB. The loading of trapezoidal boss is helpful to enhance the coupling of cavities, and the influence of the machining error is reduced to half of the original machining error influence. Finally, the filter was fabricated by the micro electromechanical system (MEMS) process, and then was tested. The test results are generally in agreement with the simulation results, which providing a reference for the design and processing of high frequency filters.

Key words: resonant column; waveguide filter; machining error; trapezoidal boss; HFSS; micro electromechanical system (MEMS)

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一种汽车碰撞试验用低阻尼宽频响加速度传感器

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摘要: 基于硅的压阻效应, 利用微电子机械系统 (MEMS) 技术研制了一种汽车碰撞试验用低阻尼、宽频响的加速度传感器。为了满足小体积和高性能的要求, 传感器采用了 L 型梁-质量块结构; 并设计了一种全方位抗过载的新颖限位结构, 保证了低阻尼传感器高过载、高可靠性。传感器芯片采用绝缘体上硅(SOI)片加工, 并利用硅硅键合与共晶键合工艺相结合实现了圆片级气密封装, 具有易于批量生产的优势, 可以广泛应用于汽车碰撞试验。封装后的传感器采用振动法和冲击法进行性能测试, 测试结果表明, 传感器的量程范围大于 2 000g, 阻尼比为 0.023, 谐振频率约 27.6 kHz, 带内平坦度在±4%范围内带宽大于 5 kHz, 传感器在多次承受 20 000g 的冲击下没有失效。

关键词: 微电子机械系统 (MEMS); 低阻尼; 压阻; 加速度传感器; 碰撞试验; 绝缘体上硅(SOI)

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A Low Damping Wide Frequency Response Range Accelerometer  
for Automobile Crash Testing

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Abstract: Based on the silicon piezoresistive effect, a kind of accelerometer with low damping and wide frequency response range was developed for automobile crash testing by the micro electromechanical system (MEMS) technology. For meeting the requirements of small volume and high performance, an L shaped beam mass block structure was adopted in the accelerometer. To ensure high overload and high reliability of the accelerometer with low damping, a new all dimensional anti overload limit structure was designed. The accelerometer chip was fabricated by using the silicon on insulator(SOI) wafer, and the wafer level hermetic packaging was achieved by the combined technology of Si-Si bonding and eutectic bonding. The accelerometer has the advantage of the mass production, thus can be widely applied in the automobile crash test. The performance test of the packaged accelerometer was carried out by the vibration method and shocking method. The test results show that the full measure range of the accelerometer is more than 2 000g, the damping ratio is 0.023, the resonance frequency is about 27.6 kHz, and the bandwidth is greater than 5 kHz with the in band flatness of ±4%. No failure of the accelerometer occurs after the repeated shocks under 20 000g.

Key words: micro electromechanical system(MEMS); low damping; piezoresistive; accelerometer; crash test; silicon on insulator(SOI)

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## MEMS 微波/毫米波 TaN 薄膜负载

### 电阻的设计与实现

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摘要: 开展了一种基于 MEMS 工艺的微波/毫米波薄膜负载电阻的结构设计和工艺实现, 该负载电阻选择 TaN 作为薄膜材料, 高阻硅为基底材料, 仿真设计并优化了三种新型结构, 给出了一套 MEMS TaN 薄膜负载电阻制备的工艺流程, 并针对该工艺流程方案进行了关键参数的工艺误差仿真, 实现了适用于 20~40 GHz 频率内的三种 MEMS TaN 薄膜负载电阻的工艺制作和测试。测试结果表明, 结构一、结构二和结构三的回波损耗分别小于-22, -18 和-18

5 dB, 并将结构一成功运用于 32~34 GHz 毫米波频段内的 MEMS 隔离器, MEMS 隔离器的隔离度大于 25 dB, 插入损耗小于 0 5 dB。MEMS TaN 薄膜负载电阻具有很好的负载吸收功能, 适合微波/毫米波通信发展需求。

关键词: 微电子机械系统(MEMS); TaN 薄膜; 负载电阻; 毫米波; 隔离器

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Design and Fabrication of a TaN Thin Film for the MEMS

Microwave/Millimeter Wave Load Resistor

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Abstract:The structure design and fabrication of a thin film microwave/millimeter wave load resistor based on the micro electromechanical system(MEMS) process were carried out. The load resistor was fabricated with the TaN thin film as thin film material and the high resistance silicon as substrate material. Three new structures were simulated, designed and optimized. A fabrication process scheme of the MEMS TaN thin film load resistor was presented. The error simulation of the key process parameters for the fabrication process scheme was conducted. Three MEMS TaN thin film load resistors used for 20-40 GHz were fabricated and tested. The test results show that the return losses of the structure 1, structure 2 and structure 3 are less than -22, -18 and -18 5 dB, respectively. And the structure 1 was successfully applied to the MEMS isolator in 32-34 GHz millimeter wave band. The isolation of the MEMS isolator is greater than 25 dB and the insertion loss is less than 0 5 dB. The MEMS TaN thin film load resistor has an excellent load power absorption function, meeting the development requirements of the microwave/millimeter wave communication.

Key words:micro electromechanical system(MEMS); TaN thin film; load resistor; millimeter wave; isolator

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灌封胶对高量程微机械加速度计封装的影响

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摘要: 封装是高量程微机械加速度传感器高可靠性的重要保障, 而灌封工艺是高量程微机械加速度传感器封装流程中一个非常重要的环节, 对实现加速度传感器产业化具有重要的影响。根据一种自制的、量程为 XX 的压阻式高量程微机械加速度传感器的封装模式, 利用有限元分析 (FEA) 方法建立加速度传感器的封装模型, 基于 FEA 方法分析了灌封热应力及灌封工艺对加速度传感器性能的影响。分析结果表明: 灌封胶的热膨胀系数和弹性模量是影响封装热应力的主要因素, 而灌封胶的密度与封装热应力无关; 灌封胶弹性模量及密度的变化对加速度传感器输出信号的影响很微弱, 可以忽略不计。

关键词: 灌封工艺; 高量程微机械加速度计; 封装; 有限元分析 (FEA); 热应力

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Effect of the Potting Adhesive on the Packaging of High g

MEMS Accelerometers

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Abstract: The packaging is the important safeguard for the high reliability of high g MEMS accelerometers, and the potting process is the critical step in the packaging process of high g MEMS accelerometers and has an important influence on the industrialization of accelerometers. According to a self made piezoresistive high g MEMS accelerometer with a measuring range of XX, the package model of the accelerometer was made by the finite element analysis (FEA) method, and the effects of the thermal stress of the potting and the potting process on the performances of the accelerometer were analyzed by the FEA method. The analysis results show that the thermal expansion coefficient and elastic modulus of the potting adhesive are the main factors on the thermal stress of the packaging, and the density of the potting adhesive has no connection with the thermal stress of the packaging. The output signal of the accelerometer is weakly affected by the elastic modulus and density of the potting adhesive, which is negligible.

Key words: potting process; high g MEMS accelerometer; packaging; finite element analysis (FEA); thermal stress

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## 紫外纳米压印技术的研究进展

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摘要: 传统的紫外纳米压印(UV NIL)虽然不受曝光波长的限制, 但是存在气泡残留、压印不均匀、模具寿命短等问题。为解决这些问题产生了各种新型 UV NIL 工艺, 针对这些工艺阐述了紫外纳米压印技术工艺要素的最新研究进展, 包括模具、光刻胶的材料与制备技术的现状, 并列举了步进-闪光压印光刻(S FIL)、卷对卷式紫外纳米压印光刻(R2R NIL)等工艺的流程及其特点。紫外纳米压印的图形质量目前仍受光刻胶填充、固化、脱模等物理行为影响。结合最近的实验研究, 从理论方面概述了紫外纳米压印的基本原理, 主要指出了光刻胶流动行为以及模具降解等问题。最后介绍了一些紫外纳米压印技术的尖端应用。

关键词: 紫外纳米压印光刻 (UV NIL); 抗蚀剂; 热压印光刻(T NIL); 步进-闪光压印光刻(S FIL); 卷对卷纳米压印光刻(R2R NIL)

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Research Progress in UV Nanoimprint Lithography Technology

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Abstract: Although the traditional UV nanoimprint lithography (UV NIL) is not limited by the exposure wavelength, it still has many problems, such as the residual bubble, nonuniform imprint pattern and short lifetime of the mould. Several novel UV NIL processes are developed to solve the problems. According to these processes, the recent research progress of process factors for the UV NIL technology are described, including materials and current fabrication processes of moulds and resists, and the processes and characteristics of the step and flash imprint lithography(S FIL), UV roll to roll nanoimprint lithography (R2R NIL) and so on are listed. The pattern quality of the UV NIL is influenced by physical behaviors of the resist filling, curing and demoulding. Based on the recent experimental studies, the basic principle of the UV NIL is overviewed theoretically, and the problems of the resist flow and mould degradation are mainly indicated. Finally, some cutting edge applications of the UV NIL are briefly introduced.

Key words: UV nanoimprint lithography (UV NIL); resist; thermal nanoimprint lithography (T NIL); step and flash imprint lithography(S FIL); roll to roll nanoimprint lithography (R2R NIL)

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低温度系数的 CrSi 薄膜电阻的制备工艺

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摘要: 采用磁控溅射法制备低温度系数 CrSi 薄膜电阻, 研究了制备过程中溅射条件对 CrSi 薄膜电阻温度系数的影响, 包括溅射功率、衬底加热温度、工艺气体体积流量和反应气体体积流量。这些条件通过改变 CrSi 薄膜这种不连续金属薄膜中的晶粒大小和晶粒间距, 进而影响 CrSi 薄膜电阻的电阻率。通过优化溅射功率、衬底加热温度、工艺气体体积流量和反应气体体积流量, 得到合适的晶粒大小和晶粒间距, 从而得到电阻温度系数为 $-3.88 \times 10^{-6}/^{\circ}\text{C}$ 的 CrSi 薄膜, 为 CrSi 薄膜电阻的集成应用提供了工艺基础。

关键词: 磁控溅射; CrSi 薄膜电阻; 温度系数; 溅射条件; 电阻率

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Preparation Process of the CrSi Thin Film Resistor with  
Low Temperature Coefficient

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Abstract: The CrSi thin film resistor with low temperature coefficient was prepared by the magnetron sputtering method. The effects of the sputtering conditions on the temperature coefficient of resistance of the CrSi thin film were investigated, including the sputtering power, substrate heating temperature, process gas volume flow and reactive gas volume flow. The resistivity of the CrSi thin film was affected by these conditions through changing the grain size and grain spacing of the discontinuous metal thin film such as the CrSi thin film. By optimizing the sputtering power, substrate heating temperature, process gas volume flow and reactive gas volume flow, the suitable grain size and grain spacing were obtained, and the CrSi thin film with the temperature coefficient of resistance of  $-3.88 \times 10^{-6}/^{\circ}\text{C}$  was prepared, which providing the technical basis for the integrated application of CrSi thin film resistors.

Key words: magnetron sputtering; CrSi thin film resistor; temperature coefficient; sputtering condition; resistivity

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基于压阻式加速度计的金属掩膜层图形化

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摘要: 干法刻蚀是压阻式加速度传感器制备中的关键工艺, 金属掩膜层的图形化对刻蚀结果尤为重要。金属掩膜层图形化的效果影响着压敏电阻条的刻蚀效果, 进而影响传感器性能。利用磁控溅射在 Si 和 SiC 衬底上分别溅射金属 Al 和 Ni 作为金属掩膜层, 并对二者的图形化效果进行对比, 同时借助激光共聚焦扫描显微镜(CLSM)观察分析金属腐蚀速率、图形化后结构的形貌、线宽损失等参数。实验证明: 对于小结构(线宽小于 50  $\mu\text{m}$ )而言, 金属 Al 由于致密性不好, 图形化后的结构模糊不规则; 金属 Ni 作为掩膜层图形化后的结构形貌清晰、形状规则、线宽损失小。

关键词: 金属掩膜; 金属图形化; 磁控溅射; 压阻式加速度计; SiC

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Patterning of the Metal Mask Layer Based on  
Piezoresistive Accelerometers

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Abstract: Dry etching is a key process in the preparation of piezoresistive accelerometers, and the patterning of the metal mask is particularly important for etching result. The patterning result of the metal mask layer influences the etching effect of the pressure sensitive resistance strips, and then affects the performances of the sensors. With the magnetron sputtering, Al and Ni were sputtered on Si and SiC substrates as metal mask layers, respectively, and the patterning results of the two metal mask layers were compared. Meanwhile, the parameters were observed and analyzed by the confocal laser scanning microscope (CLSM), including the corrosion rate of metals, the shape of the patterned structure, the loss of line width and so on. The experimental results show that for small structures(the line width is less than 50  $\mu\text{m}$ ), the patterned structure of Al is fuzzy and irregular owing to its poor compactness. As a mask layer, the patterned metal Ni has the advantages of clear structure, regular shape and small line width loss.

Key words: metal mask; metal patterning; magnetron sputtering; piezoresistive accelerometer; SiC

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