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硅基微纳器件加工技术研究

Fabrication of Silicon Based Micro and Nano Devices

杨文

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摘 要

微纳米材料表现出许多传统材料所不具备的新特性，随着科学技术的不断进步，纳米技术已然成为了最热门的研究领域之一。集成度的提高依赖于微纳米器件的尺寸的进一步缩小，微纳米加工技术的提高是器件尺寸缩小的基础。微纳米加工技术主要可以归为三类：平面工艺、探针工艺以及模型工艺。平面工艺是指利用光刻将图形转移到光刻胶并采用刻蚀或者沉积技术等将图形转移到基片表面形成结构复杂的微纳米器件，主要工艺包括光刻、刻蚀、薄膜沉积等。探针工艺是不仅可以指采用传统探针(扫描电镜探针、原子力显微镜探针)在基片表面加工出微纳米结构，还包括采用聚焦离子束、激光束等在基片表面剥离形成微纳结构。模型工艺是指使用微纳米量级的模具复制出相应的纳米结构，例如纳米压印。本论文围绕着平面工艺，探究了KOH腐蚀形成硅探针针尖过程并采用湿法腐蚀工艺制备SiO2微盘腔，使用光刻和感应耦合等离子体(ICP)刻蚀制备八台阶红外焦平面微透镜阵列，主要内容和成果如下:

1. 研究了KOH溶液对硅的各向异性腐蚀形成凸台面和针尖的物理过程，通过俯视SEM和断面SEM推断出针尖的形成过程。测量得到了腐蚀晶面与(001)面形成的八边形内角和晶面的倾角，经过与理论值比较，表明实验中腐蚀的晶面是{311}晶面族。在本论文实验条件下，测量计算出{311}面的腐蚀速率约为0.6 μm/min。进一步腐蚀得到由{311}晶面族形成的硅针尖，纵横比约为1.7:1，硅针尖曲率半径约为50 nm。本研究确定了腐蚀晶面为{311}晶面族，并澄清了一些文献中的错误结果。

2. 研究了KOH腐蚀制备SiO2微盘腔工艺，采用SEM表征微盘腔的形貌特性，微盘腔边缘呈楔形，有利于Q值的提高。通过光纤锥与微盘腔耦合进行测试，得到了微盘腔的透射谱，计算得到了微盘腔的Q值约为1×104，自由频谱范围(FSR)为9.6 nm。利用AFM表征微盘腔上表面，所得RMS仅为0.469 nm。

3. 研制了硅八台阶微透镜阵列，其制作难点在于套刻和ICP，通过采用对版标记差异化设计及选择性去除对版标记上的光刻胶提高了光刻的套刻精度。并优化了ICP刻蚀条件与时间，减小了ICP刻蚀出的台阶的高度误差。在微透镜的背面减薄抛光把硅片的厚度减到100 μm，并采用双面光刻在背面制作圆孔金属铝光阑，通过

自制的简易测试系统测量到微透镜的衍射效率约为86%。

关键词：硅；微纳结构；探针；微盘腔；微透镜阵列

Abstract

Micro-nano structures exhibited lots of novel characters, which traditional materialsdo not have. Nanotechnology has become one of the most popular research areas. The increase of integration level depends on the further miniaturization of the micro-nano devices, The improvement of micro-nano processing technology is the basis for device size reduction. Micro-nano processing technology can be classified into three categories: planar process, probe process and model process. Planar process refers totransferringpatterns from photolithography mask to the substrate surface to form a complex structure of micro-nano devices by etching or deposition. The main process included lithography, etching, film deposition and so on. The probe process not only refers to the use of conventional probes (scanning electron microscopy probes, atomic force microscopy probes) to manufacture micro-nano devices on the substrate surface, but also the use of non-solid probe, such as focused ion beams, laser beam. The model process refers to the use of micro-nano-scale molds to reproduce the corresponding nanostructures, such as nano-imprinting. The main contents of this dissertation are as follows:

1. The formation of convex surface and tips of silicon materials by KOH solution: Silicon anisotropy was studied. The formation mechanism of needle tip was studied by crosssectional and plan-view SEM. The crystal facets during the anisotropy etching was identified to be {311} plane family by SEM images and also the geometry calculation. The etching rate of the {311} plane is about 0.6 μm / min. Silicon tipswith {311} inclined crystal facetswas also obtained with 1.7: 1, aspect ratio.The radius of curvature of the silicon tip was about 100 nm.

2. The manufacture process of SiO_2 microdisk cavity by KOH etching was studied. The morphological characteristics of SiO_2 microdisk were characterized by SEM, and the hems of microcavity was wedge-shaped, which was beneficial to

the quality factor. The tapered optical fiber was coupled with the micro-disc cavity to obtain transmission spectrum. The Q value of the microcavity was calculated to be about 1 × 104 and the FSR was 9.6 nm. The total roughness of the microcavity was 395 nm deduced by Q value. The roughness of the microcavity was mainly caused by the side wall and the lower surface.

3. The difficulty of making the eight-step microlens array lied in the alignment of photoetching and ICP. In this dissertation, we optimized the photolithography and ICP processes to fulfill the complicate structure. The microlens wafer was finally thinned to be only 50μm with circle aluminum aperture on the backside. The diffraction efficiency of our microlens was measured to be 86%.

Keywords: silicon; micro-nano structure; probe tip; WGM microdisk ; infrared microlens array

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