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多孔GaN/MoO_3异质结窄带响应紫外光电探测器

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摘　要

紫外光电探测器在空间天文望远镜、军事导弹预警、非视距保密光通信、野外火灾遥感和生化检测等方面具有非常广泛的应用前景。本文介绍了一种基于GaN纳米孔阵列/MoO_3异质结紫外光电探测器。通过简单的光电化学刻蚀方法，将平面u-GaN刻蚀成均匀的纳米孔，以减少表面缺陷，增强光吸收。在多孔GaN材料上沉积MoO_3薄膜，制成多孔GaN/MoO_3异质结。实验结果表明，该紫外光探测器在−3 V偏压下的光开/关比超过10^3；与纯多孔GaN器件相比，异质结器件的响应度和外量子效率均提高了两个数量级。此外，该异质结器件具有窄带响应，半峰宽度仅10 nm。这种具有高开关比、高量子效率和窄带响应特性的光电探测器有望实现在荧光检测、成像和紫外光通信方面的应用。

关键词

紫外光电探测器，多孔GaN，异质结，窄带响应

Narrow-Band UV Photodetector Based on Porous GaN/MoO_3 Heterojunction

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Abstract

UV photodetectors have very broad application prospects in space astronomy, military missile

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early warning, non-line-of-sight confidential optical communication, remote sensing and biochemical detection etc. In this paper, a porous GaN/MoO_3 heterojunction UV photodetector is introduced. By a simple photoelectrochemical etching method, planar u-GaN was etched into uniform nanopores to reduce surface defects and enhance light absorption. The porous GaN/MoO_3 heterojunction was then constructed by depositing a thin MoO_3 film. Results show that the UV photodetector has a high light-to-dark of more than 10^3 at −3 V bias; while the responsivity and external quantum efficiency of the heterojunction device are improved by two orders of magnitude compared to the pure porous GaN device. In addition, the heterojunction device exhibits a narrow-band response with a FWHM of only 10 nm. This porous GaN/MoO_3 photodetector featuring high on/off ratio, high quantum efficiency and narrow-band response characteristics may find applications in fluorescence detection, imaging and ultraviolet optical communication.

Keywords

UV Photodetector, Porous GaN, Heterojunction, Narrow-Band Response

1. 引言

紫外光电探测器在空间天文望远镜、军事导弹预警、非视距保密光通信、野外火灾遥感和生化检测等方面具有非常广泛的应用前景[1] [2] [3] [4]。基于半导体的光伏效应，半导体在光照作用下产生光生载流子，在外加或者内建电场作用下进行扩散或漂移运动，形成光电流，从而可实现光电信号的转换[5] [6]。

GaN 作为第三代半导体材料，具有禁带宽度大、耐高温、载流子迁移率高等特点[7] [8]。目前 GaN 基高性能紫外光电探测器已实现商用，其光吸收材料普遍采用外延生长的 GaN 薄膜，但异质外延生长的 GaN 薄膜仍然具有较大的残余应力和晶格缺陷，这对器件性能进一步提升存在限制[9] [10] [11]。为了降低缺陷密度和残余应力，采用化学或电化学方法在缺陷处进行刻蚀，形成多孔结构是改善材料质量的一种可行方法[12] [13] [14]；而且多孔 GaN 具有更大的表面/体积比和更优异的光吸收/发射特性，这些特性使多孔 GaN 在气体和光电探测器、发光器件和太阳能电池等领域有潜在应用[15] [16] [17]。

基于此，我们报道了一种多孔 GaN/MoO_3 异质结紫外光电探测器。我们采用离子液湿法光电化学刻蚀制备多孔 GaN，与干法刻蚀相比，降低了 GaN 材料表面缺陷和残余应力的同时，保证材料晶体不受刻蚀损伤。通过在多孔 GaN 上热蒸发的 MoO_3 层，形成多孔 GaN/MoO_3 异质结，进一步增强光生载流子的分离过程。所构建的紫外光电探测器，对紫外光表现出高光电响应、高开关比，并具有优异的窄带响应特性。

2. 实验

2.1. 多孔 GaN 薄膜制备

用丙酮、乙醇和去离子水清洗氮化镓薄膜，InGa 合金做正极，Pt 做负极，将 GaN 片与铂片浸泡在离子液(1-乙基-3-甲基咪唑三氟甲磺酸盐)中并置于氙灯前照射，直流电源电压设为 15 V，时长为 10 min。

2.2. 多孔 GaN/MoO_3 异质结器件制备

用高温胶带覆盖部分多孔 GaN 薄膜表面，置于热蒸发设备中制备 MoO_3 薄膜，腔内压强为 5×10^4 Pa，

蒸发速率为 0.1~0.3 Å/s。在多孔 GaN 和 MoO_3 薄膜上分别制备 InGa 电极和 Ag 电极，有效光敏面积约为 0.01 cm^2。

2.3. 测试表征

材料的微观形貌采用电子扫描显微镜(Nova Nano SEM430)进行表征，器件光电性能采用紫外光电测试系统(SCS10-EQ99-DSR)进行表征。所有测量都是在室温环境条件下进行的。

3. 结果与讨论

图 1(a)给出了均匀的多孔 GaN 表面形貌，从图中我们可以看到蜂窝状的孔洞结构。多孔 GaN 的成机理是：在 300 W 氙灯光照作用下，GaN 中的光生电子从价带激发到导带，在电场作用下电子和空穴在液固界面分离，于是在 GaN 界面处出现的大量空穴而将 GaN 表面氧化，N 原子与 Ga 原子之间的三键出现断裂现象，使 Ga^{3+}溶解到电解液中，形成多孔网络。图 1(b)为多孔 GaN 上热蒸发沉积 MoO_3 层，从而构建出多孔 GaN/MoO_3 异质结。

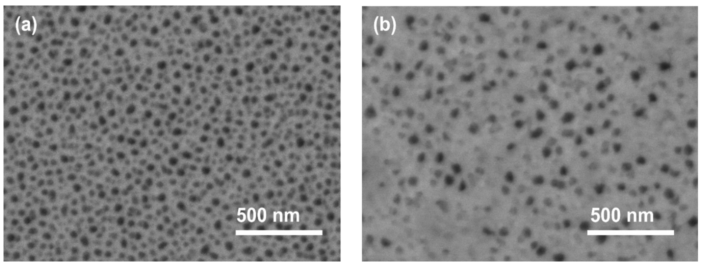

Figure 1. SEM images of (a) pure porous GaN after etching 10 min; (b) surface morphology of MoO_3 depositing on porous GaN
图 1. SEM 图。(a) 刻蚀时间为 10 min 形成多孔 GaN 表面；(b) MoO_3/多孔 GaN 表面形貌

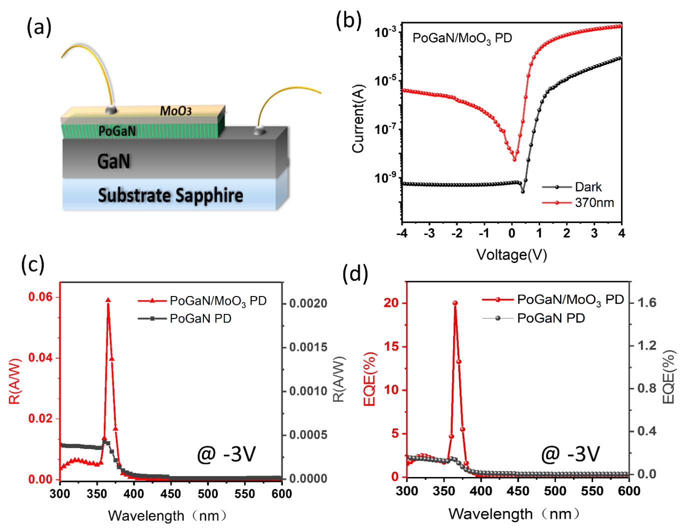

Figure 2. Structure and performance characterization of GaN/MoO_3 heterojunction UV photodetectors. (a) Schematic diagram of the device; (b) Light and dark I-V curves; (c) Responsivity and (d) External quantum efficiency spectra of the porous GaN/MoO_3 heterojunction device at −3 V, with the pure porous GaN device as a reference
图 2. GaN/MoO_3 异质结紫外光电探测器器结构与光响应性能表征。(a) 器件结构示意图；(b) 光、暗 I-V 特性曲线；(c) −3 V 电压下的多孔 GaN/MoO_3 异质结器件和纯多孔 GaN 器件的响应度谱；(d) −3 V 电压下的多孔 GaN/MoO_3 异质结器件和纯多孔 GaN 器件的外量子效率谱

分别在 GaN 层和 MoO_3 层上制备 InGa 电极和 Ag 电极，GaN/MoO_3 异质结紫外探测器示意如图 2(a)所示。图 2(b)给出了多孔 GaN/MoO_3 异质结探测器在黑暗和紫外光照射下(370 nm，功率密度为 6.25×10^{-4} W/cm^2)的 I-V 特性曲线。可以观察到，在正向和反向偏压下，暗电流曲线呈现不对称形状，显示出显著的整流特性，说明 GaN/MoO_3 P-N 异质结的形成。另外，在 370 nm 光照和−3 V 偏置下，器件的输出电流从暗态的 5.26×10^{-10} A 增加到 2.83×10^{-6} A，光暗电流比超过 3 个数量级，表现出显著的光响应。

响应度和外量子效率是评估器件光响应性能的关键参数[18] [19] [20]。如图 2(c)和图 2(d)所示，在−3 V 偏压下，GaN/MoO_3 异质结器件的峰值响应波长为 370 nm，峰值响应度为 0.06 A/W，峰值外量子相率为 20.3%。作为对比，纯多孔 GaN 器件(图中黑色点划线)的峰值响应度和外量子效率仅为 5×10^{-4} A/W 和 0.5%。与纯多孔 GaN 器件相比，GaN/MoO_3 异质结器件峰值响应度和外量子效率均提升了两个数量级。此外，我们还发现 GaN/MoO_3 异质结器件的窄带响应特性，其响应谱范围为 355 nm~380 nm，半峰宽仅 10 nm，表明了该器件在紫外区具有高光谱选择性。GaN/MoO_3 异质结器件的性能提升主要归因于多孔 GaN 晶体质量的改善和异质结的形成，光生载流子在异质结内建电场的作用下，实现高效分离；此外，采用湿法刻蚀多孔 GaN，改善了光的吸收特性。

4. 结论

本文展示了一种基于多孔 GaN/MoO_3 异质结的高性能紫外光电探测器。我们采用湿刻法刻蚀多孔结构，降低材料缺陷、提高晶体质量、改善光吸收；通过构建多孔 GaN/MoO_3 异质结增强光生载流子的分离。所制备的多孔 GaN/MoO_3 紫外光电探测器在−3 V 偏压下光开/关比超过 10^3，响应度可达 0.06 A/W，外量子效率可达 20.3%，与纯多孔 GaN 器件相比，异质结器件的响应度和外量子效率均提高了两个数量级。此外，该器件还展现出独特的窄带响应特性。这种具有高开关比、高响应和窄带响应特性的紫外光电探测器有望在保密通讯等领域实现应用。

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