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Gold coated microstructures as a platform for the preparation of semiconductor-based hybrid 3D micro-nano-architectures

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Abstract In this paper, three types of microstructures are argued as substrates for electrochemical deposition of Au nanodots. They include: (a) aero-GaN consisting of hollow GaN microtetrapods, (b) microdomains of pores with a controlled design produced by anodization of InP wafers, and (c) patterned microdomains composed of strips with alternating electrical conductivity in GaN crystals grown by hydride vapor phase epitaxy. Uniform deposition of Au nanodots with controlled density is demonstrated by using pulsed electroplating, the voltage pulse width and amplitude as well as the pause between pulses and the conductivity of the substrate serving as adjustable parameters. The morphology of the produced hybrid microarchitectures was investigated by scanning electron microscopy. The explored microstructures are proposed as platforms for the development of complex 3D hybrid micro-nano-architectures via the vapor–liquid–solid deposition of various semiconductor nanowires with Au nanodots as catalysts.

1 Introduction

Various functional nanowires with bandgap covering the spectral range from near infrared (NIR) to ultraviolet (UV) have been grown on a variety of semiconductor substrates by means of catalyst-assisted or self-catalyzed vapor–liquid–solid (VLS) processes. In the catalyst-assisted processes, Au is the most frequently used catalyzer. As concerns the technologies applied in the VLS process, they include molecular beam epitaxy (MBE), chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), metalorganic vapor phase epitaxy (MOVPE) or metal organic chemical vapor deposition (MOCVD) and hydride vapor phase epitaxy (HVPE).

InP and GaAs nanowires belong to semiconductor materials with the bandgap in the NIR spectral range. They have been produced both with Au catalyst and by self-catalyzed VLS process on various substrates. InP nanowires have been grown with In droplets in the self-catalyzed VLS process on Si substrates by MOCVD technology [1] and on InP substrates by MOVPE method [2]. With Au catalyst, InP nanowires have been grown by MOVPE technology on InP [3], MoS_2 [4], and quartz [5] substrates. InP nanowires have also been grown by MBE with Au-In droplets as catalyst on Si substrates [6]. Apart from pure InP nanowires, InAs/InP quantum rod nanowires were grown on Si substrate [7], InAs/InP quantum-disk nanowires were grown on InP substrates [8], and alternating InAsP/InP heterostructure nanowires with multiple-quantum-dot structures were grown on InP substrates [9] with Au catalyst. InP nanowire stems with InSb nanoflags have been grown with Au catalyst for quantum devices [10].

GaAs nanowires have been grown with Ga droplets in the self-catalyzed VLS process on Si substrates by MBE technology [11–13]. With Au catalyst, GaAs nanowires have been grown by HVPE technology on GaAs [14], by MOVPE technology on GaN [15], and by MOCVD technology on SiN [16] substrates. Apart from pure GaAs nanowires, axial GaAs/Ga(As, Bi) heterostructures were grown on Si substrates [17], GaAs/(InGa)As/GaAs axial double-heterostructure nanowires [18], core–shell GaAs-AlGaAs nanowires [19] and GaAs/GaSb core–shell heterostructured nanowires [20] were grown on GaAs substrates, and InAs/GaAs core–shell nanowires were grown on InAs substrates [21] with Au catalyst.

GaP nanowires with the bandgap in the visible spectral range have been grown with Ga catalyst in the self-catalyzed VLS process on Si substrates by MBE technology [22]. With Au catalyst, GaP nanowires have been grown by MOVPE [23] and by MBE technologies [24] on Si substrates, as well as by MOVPE [25] and by solid-source sublimation method [26] on GaP substrates. Apart from pure GaP nanowires, axial hybrid GaP/Si nanowires [27] and core–shell GaP/GaPN nanowires [28] were grown on GaP substrates with Au catalyst.

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GaN, ZnO, and ZnS nanowire structures were grown for the UV spectral range applications. GaN nanowires were grown with Ga droplets in the self-catalyzed VLS process on Si substrates using CVD technology [29]. With Ga-Au-In alloy catalyst, GaN nanowires were grown by MOCVD on GaN and sapphire substrates [30]. With Ni catalyst, GaN nanowires were grown by CVD on sapphire substrates [31]. HVPE technology was applied to grow GaN nanowires on Si substrates with either Au catalyst [32], or with Ni-Au catalyst [33]. In addition to pure GaN nanowires, GaN/InGaN core/shell multiple quantum well (MQW) co-axial heterostructure nanowires were grown on a variety of sapphire, silicone, copper, tungsten, glass, gallium nitride, and beryllium oxide substrates [34]. ZnO nanowires were grown with Au catalyst by carbothermal reduction method on Si substrates [35, 36], by vapor phase deposition [37] and by mist-CVD [38] on GaN substrates. In addition to pure ZnO nanowires, ZnO-ZnMgO core–shell nanowires have been grown on sapphire with Au catalysts [39]. ZnS nanowires [40, 41] and ZnS nanotubes [42] were grown by thermal evaporation of ZnS powder on Si substrates with Au catalysts. ZnS nanowires were also grown by MOCVD on GaAs substrates with Au catalysts [43]. Apart from pure ZnS nanowires, ZnS/diamond-like carbon (DLC) core–shell heterostructure nanowires [44] and ZnS/SiO_2 core–shell nanowires [45] were fabricated on Si substrates with Au catalysts. GaN/ReS_2, ZnS/ReS_2 and ZnO/ReS_2 core–shell nanowire heterostructures were produced by CVD on SiO_2/Si wafers with Au catalysts [46].

The variety of semiconductor nanowire structures produced with Au catalyst-assisted VLS growth on various substrates, covering a wide spectral range, constitutes a powerful platform for many applications in electronics, optoelectronics, photonics, energy, photocatalysis, piezoelectric generators, sensors etc. At the same time, most of these nanostructures were prepared on flat substrates. Deposition of semiconductor nanowire arrays on microstructures with controlled design and morphology, would result in more complex micro-nano-structure assemblies, which are expected to enlarge even more their areas of applications.

The goal of this paper is to demonstrate some 3D microstructure platforms with Au nanodot coatings for subsequent growth of semiconductor nanowires and other applications.

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