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Aging effect of rolled-up InGaAs/GaAs/Cr helical nanobelts

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ABSTRACT

We report an aging effect on as-fabricated InGaAs/GaAs/Cr helical nanobelts. It has been observed that over time the nanobelt diameter first decreases and then increases until a constant value is reached. The gradual change of the diameter of the helical nanobelts from their original value is due to the competition of stress relaxation along the transverse and longitudinal axes of the nanobelts. Finite element modeling (FEM) has been applied to validate the influence of the biaxial stress relaxation on the curvature change of these rolled-up helical nanobelts. In addition, the dependence of the pitch of the helix over time is investigated as well.

1. Introduction

A technique for fabricating three dimensional (3D) structures by a combination of "top down" and "self-organization" approaches, known as the self-scrolling technique, was introduced by Prinz et al. in 2000 [1]. This method is based on the coiling up of strained 2D thin films to generate 3D structures, an element of self-organization, after detachment from a substrate by selective etching. Using the self-scrolling technique, 3D micro-/nanostructures such as tubes and helices are fabricated in a controllable fashion [1–4]. Previously, it has been found that the diameter of the rolled-up micro-/nanotube can be precisely estimated theoretically, because the initial biaxial stress in the thin films are partially relaxed along the rolled-up direction [5], i.e. a uniaxial stress relaxation condition. In contrast to rolled-up tubes, the stress relaxation condition becomes more complicated for a rolled-up helical nanobelt in which the diameter, chirality, and pitch are also related to the width of the nanobelt due to the biaxial stress relaxation in the film plane [6,7]. Previous results indicated that the diameter of the helical nanobelts tends to increase as the stress relaxation condition changes from uniaxial to biaxial [6–8]. The robust fabrication process and the ultra-flexibility demonstrated for helical nanobelts have resulted in their application as nanosprings and linear-to-rotary motion converters [9–11]. Since diameter and pitch are two key geometrical parameters which determine the spring constant of the nanospring [12] and the conversion ratio of the linear-to-rotary motion converter [11], the stability of geometrical parameters of the helical nanobelts over time is important in determining the reliability of the devices. In this paper, the aging effect of InGaAs/GaAs/Cr helical nanobelts is investigated. Finite element analyses are also applied to analyze curvature dependence on the biaxial stress relaxation of the rolled-up helical structures.

2. Experimental methods

Freestanding InGaAs/GaAs/Cr helical nanobelts have been fabricated using the following procedure. First, AlGaAs/InGaAs/GaAs layers with thicknesses of 400 nm/16 nm/11 nm are epitaxially grown on a GaAs (001) substrate by molecular beam epitaxy (MBE) in which the AlGaAs layer acts as a sacrificial layer for releasing the InGaAs/GaAs bilayer from the substrate. The In concentration is 14% measured by X-ray diffraction (XRD), thus the misfit strain is 1.0% in the bilayer. Then a Cr layer is deposited on the top GaAs layer by e-beam evaporation with a thickness of 15 nm or 30 nm. For photolithographic patterning, photoresist S1818 (Shipley) is used for the generation of initial ribbon patterns, and then a mixture of Cl_2 and H_2 gases are employed for reactive ion etching (RIE) to transfer the patterns from the photoresist to the underlying layers. The main advantage of Cl_2 gas is its high etch rate on Cr and GaAs based materials [13]. The gap between the helical structure and the substrate should be large enough to avoid the helical structures sticking onto the substrate. Unlike the fabrication of freestanding Si-based helical nanobelts in which deep trenches are formed by wet etching of Si substrate [7], for fabricating freestanding GaAs based 3D structures on GaAs substrate, the trenches are created by RIE. Experiment results show that if the trench depth is larger than 1 μm, the as-fabricated 1–4 turn helices are freestanding. After oxygen plasma cleaning of the residue photoresist, a 1% HF aqueous solution is used to etch the AlGaAs

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