Laser etching of quasi-1D TiS_3 nanoribbons by Raman spectrophotometer

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ABSTRACT

In this work, we study the laser etching capabilities of TiS_3 nanoribbons by Raman spectrophotometer laser. The experiments were carried out with different nanoribbons with a thickness varying from 100 to 150 nm, prepared on a silicon substrate via mechanical exfoliation technique. The resulting etching depth was in the range of 20-25 nm with no oxidation. We also observed significant, up to 3-4 nm improvement of the surface roughness of etched samples, which makes the laser etching promising for the development of flexible, efficient, and reliable optoelectronic devices.

1.INTRODUCTION

Transition metal dichalcogenides (TMDs) has drawn a lot of attention because of their layered structure and thus their suitability for a variety of applications [1]. One of the important semiconducting members of trichalcogenides family is titanium trisulfide (TiS_3), which has recently drawn the interest of the 2D community because of its remarkable photoresponse and its direct bandgap of ~1.0 eV, close to that ofsilicon, providing promise for optoelectronics [2].

Mechanical exfoliation, liquid- phase exfoliation, chemical vapor deposition (CVD), molecular beam epitaxy, electrochemical thinning are usually used for processing ultrathin 2D materials with a sufficient number of layers. Recently, laser thinning has emerged as a promising and alternative fabrication method [3]. It is an efficient and simple top-down method to thin and fabricate specific patterns using appropriate environment and a controllable laser power level.

In this work, we study the possibilities of thinning of TiS_3 nanoribbons by the laser installed in a Raman spectrophotometer. The spectrophotometer simplifies positioning and focusing of the laser on particular parts of nanoribbons, and gives good control over the laser power.

2. SAMPLE PREPARATION

TiS3 nanoribbons were synthesized by chemical vapor transport method. (CVT). This method is based on a solid-gas reaction between titanium powder (2 g, Good fellow, 99.5% purity) and sulfur gas produced by heating of sulfur powder (6 g, Merck, 99.9% purity). whiskers were then transferred to the underlying substrate via the micromechanical exfoliation method using scotch tape. The ribbons were exfoliated on top of a SiO_2 on Si wafer, with a SiO_2 thickness of 285 nm.

Prior to the transfer process, the SiO_2/Si substrate was cleaned using sonication in acetone, isopropyl alcohol, and deionized water.

3. RESULTS AND DISCUSSION

The experimental setup used for laser etching and Raman measurements was a confocal scanning Raman microscope Horiba LabRAM HR Evolution (HORIBA Ltd., Kyoto, Japan) operating at a wavelength of 532 nm.

All the Raman spectra were collected using linearly polarized excitation laser, through a 100× objective (NA ≈ 0.9) with a laser spot size of about 0.43 μm, 1800 lines/mm grating.

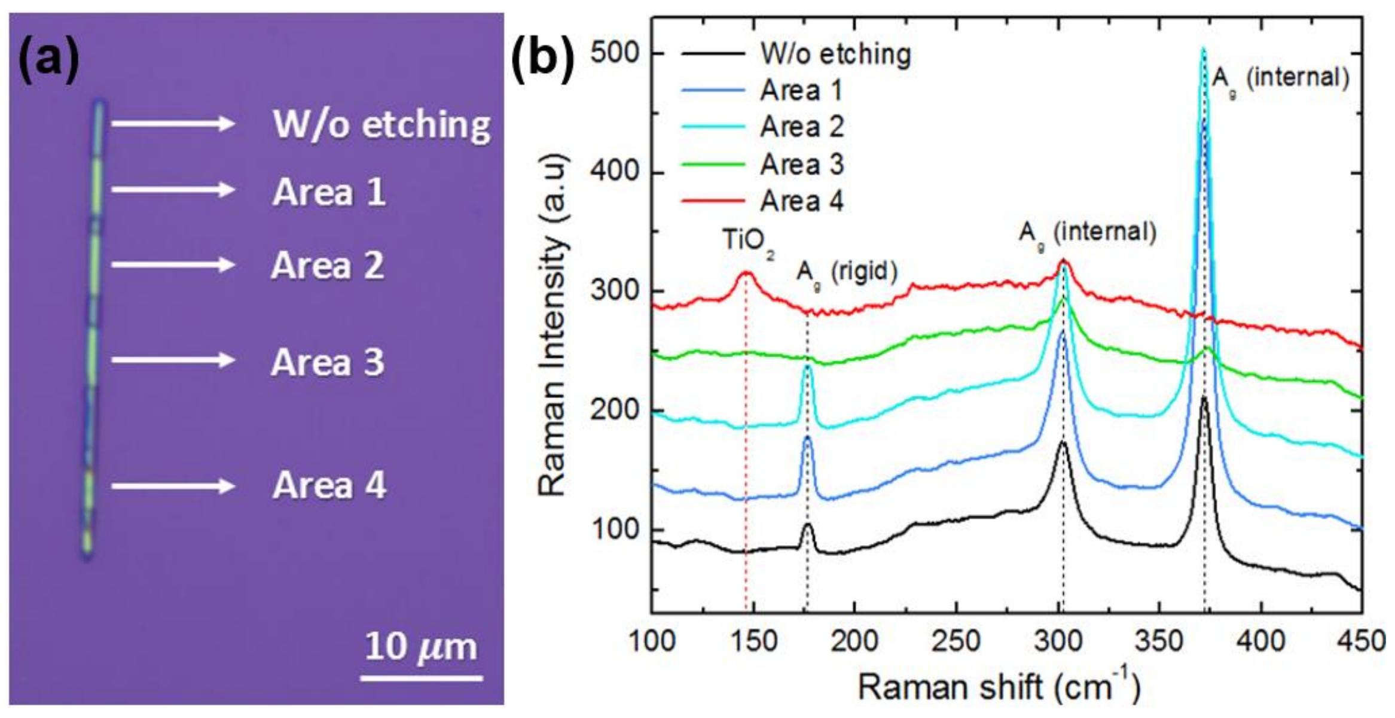

Figure 1. Nanoribbon etched with laser thinning, a - optical image with etched and non-etched areas, b - Raman spectra collected from those etched regions of the nanoribbon.

The experiments were carried out among nanoribbons with a thickness of 100-150 nm. For such samples, the maximum thinning before oxidation is possible in the range of 20-25nm. The laser thinning processes were carried out within different areas of the ribbons under various experimental parameters, including exposure time, irradiation step, and percentage of laser power supplied to the samples.

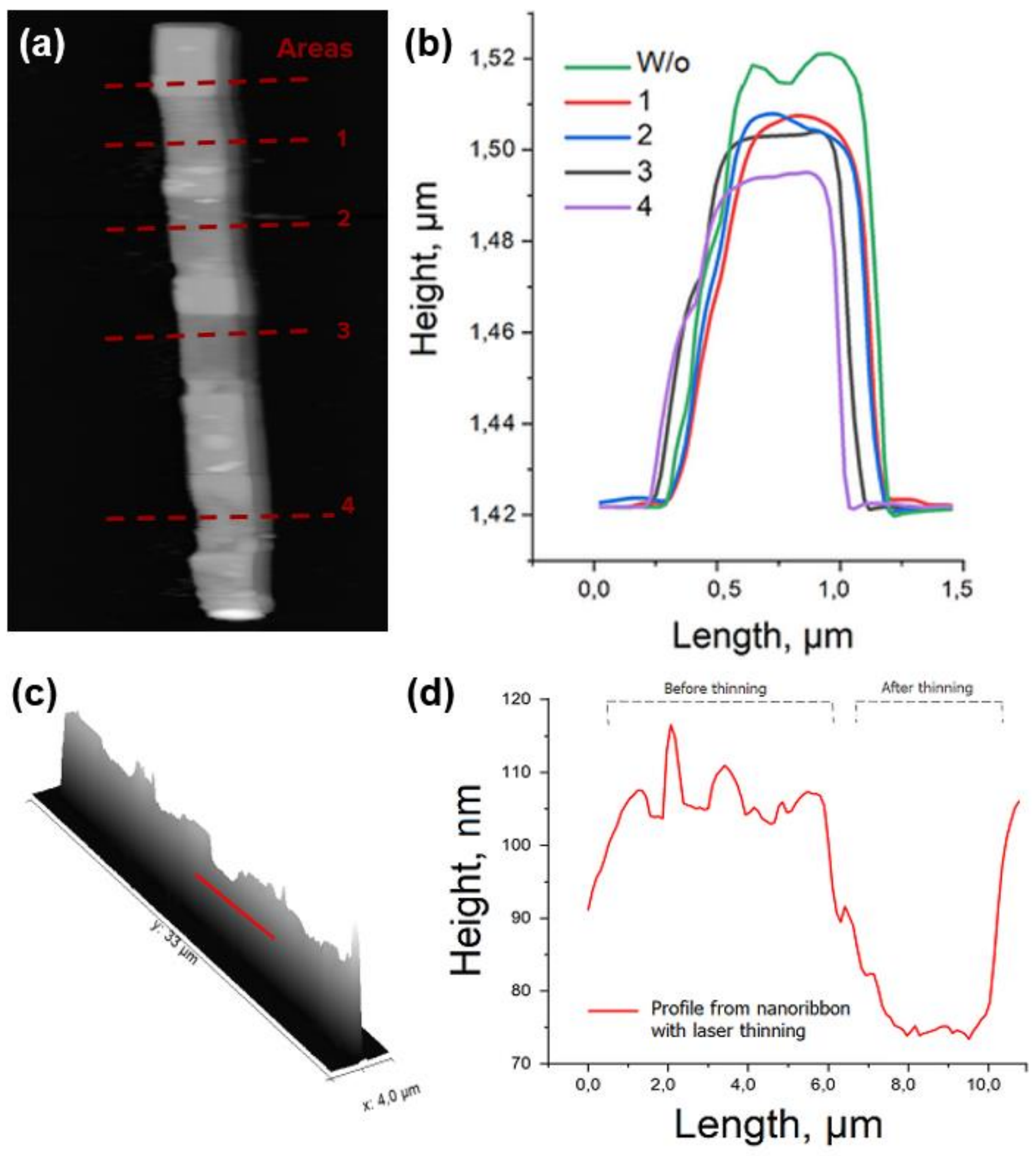

Figure 2. AFM maps from etched and intact nanoribbons. a) - 3D topography of the whole nanoribbon, without laser exposure, b) the profile of the nanoribbon from fig. (a) full length, c) nanoribbon with etched areas, correspond to the numbers on the graph (d)., e) 3D topography of the nanoribbon with etched areas, f) - nanoribbon profile from fig.(e)

Process	Exposure time (Sec.)	Irradiation step (nm)	Applied powers (mW)
Area 1	0.5	400	1.5
Area 2	0.5	400	3
Area 3	1	400	3
Area 4	0.05	400	7.5

Table 1. Parameters of laser etching of regions labeled in Fig. 1a.

The thickness of the nanoribbon shown in Fig. 2awas 110 nm. For the first layer- thinning process, the parameters listed in Table 1, were sufficient to etch approximately 10 nm of an intact nanoribbon.

The main spectra of the sample is taken with a threshold power of 0.75 mW. This value is suitable for obtaining clear spectra of the main TiS_3 peaks and also remains insufficient to induce any thinning within the ribbons. For the laser thinning process, the radiation power varied from 1.5 to 7.5 mW for an exposure time from 5 to 0.05 s. Parameters for each thinning process are demonstrated in Table 1. The roughness of the nanoribbon after etching is improved by 3 to 4 nm compared to the roughness of the nanoribbon before etching (Fig. 2d, f). So, the laser thinning can be applied to corrugated surfaces without prior polishing.

4. SUMMARY

we studied the possibility of layer thinning of TiS_3 nanoribbons by the laser of the Raman spectrophotometer. up to twenty layers can be etched before oxidation of the sample occurs. The ribbons etched by the laser-thinning process have straighter edges and are smoother than the un-etched one.

ACKNOWLEDGEMENT

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