Electrical properties of silicon nanodots embedded in a SiC matrix for photovoltaic applications

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Introduction

Efficiency increasing and cost reduction are key concepts in the development of the photovoltaic field and one of the factors responsible for power loss in single bandgap solar cells is that, for photons with energy higher than the band gap, the excess energy is lost by thermalization. One way to overcome this limit is to introduce the multijunction concept, where the device has more than one bandgap [1]. In this framework, silicon nanocrystals (Si NCs) embedded in a dielectric matrix were proposed as absorbers in all-Si multi-junction solar cells thanks to the quantum confinement capability of the Si NCs, that allows a better match with the solar spectrum [2,3]. SiC as a dielectric matrix is considered promising thanks to its better conduction properties and lower barrier to the Si NCs with respect to e.g. SiO_2 [1].

Current-Atomic Force Microscopy (c-AFM) is widely used to determine the local electrical properties of semiconducting thin films at the nanoscale [4]. A conductive probe is put in contact with the surface and the current flowing between the tip and the sample is measured at constant bias [4]. In the present contribution c-AFM has been used to characterize features related to Si NC clusters in SiC on a local scale, giving a fundamental insight on their properties at microscopical level.

Materials and Methods

Silicon Rich Carbide (SRC)/SiC multi-layers are deposited by Plasma Enhanced Chemical Vapor Deposition on quartz. The precursor gases used are SiH_4, CH_4 and H_2, the temperature of the substrate is 325°C. The multi-layers are composed by a stack of 30 bi-layers of SRC and SiC. The silicon fraction in the SRC layers is 0.85. The thickness of the as-deposited layers is 9 nm for SiC and varies between 2 and 4 nm for SRC. A sacrificial a-Si:H layer (20 nm thick) is deposited on top of the shallowest SiC layer in order to prevent SiC surface oxidation during the subsequent annealing for Si NC formation [5], which is performed at 1100°C for 30 minutes. A wet etching is performed subsequently in order to remove the sacrificial layer [6]. Parallel Ni contacts are evaporated for current-voltage measurements. A dry etching (SF_6+0_2, 20 s) is used to remove the shallowest SiC layer from the surface before local conductivity measurements.

AFM (NT-MDT Solver P47H Pro microscope) is performed in contact mode to measure the surface topography and the local conductivity. The probe used is a conductive, Pt coated tip, with nominal radius of curvature of 35 nm.

Results and Conclusions

Current-AFM is the technique used to measure the local conductivity of the sample to identify the current paths at the nanoscale. A 1x1 μm^2 map taken on the sample with SRC layer thickness of 4 nm is shown in Figure 1.a. The bias applied to the tip is +2 V and the current ranges between 0 and 100 pA. The darker areas in the image correspond to higher conductivity. Regions with different conductivity can be noted. These regions are not directly correlated with some topographical features, therefore morphology-related artifacts can be excluded. Similar behaviors observed for the samples with different SRC layer thickness. Considering that in this material different phases (amorphous and crystalline) and compositions (SiC and Si) coexist, the differences in the local conductivity can be related to phase or compositional variations. Moreover, the role of impurities and/or to unintentional doping by contamination with N and O could be envisaged. The map shows cluster (likely related to Si or SiC NCs) with different conductivities embedded in a quite uniform matrix. We could attribute the different conductivity of the clusters to compositional variation (Si content) and/or impurity contamination, as also observed in nc-Si:H [7].

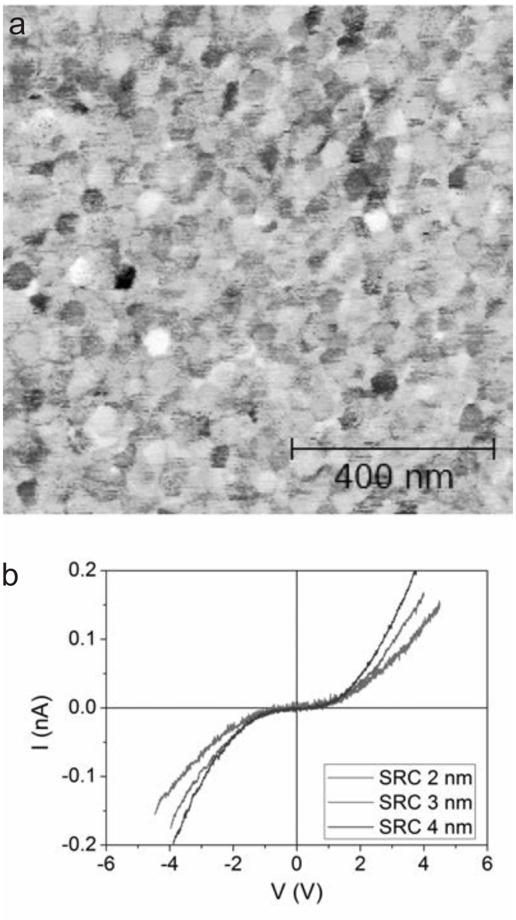

Figure 1. (a) C-AFM performed on sample with SRC layer thickness of 4 nm. (b) Local IV measured with AFM for different SRC layer thickness. Each curve is the average of 10 measurements taken in different positions on the sample surface.

IV characteristics have been measured locally with AFM in contact mode. The curves are shown in Figure 1.b and show a defined trend: at the same bias the current increases with increasing SRC layer thickness. It is possible to compare this result with the lateral conductivities measured with the deposited Ni contacts. The conductivity increases from $9.3\cdot10^{-6}$ S/cm to $1.7\cdot10^{-5}$ S/cm with increasing SRC layer thickness (2-4 nm), showing the same trend of the local measurements [8].

c-AFM is used to characterize the electrical properties of the multi-layers, showing variations at the nanoscale in the conductivity. Local IV measurements show a defined trend with SRC layer thickness, in agreement with what is observed for the lateral conductivity.

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