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LETTER

Response to comments on "Enhancing the Photovoltaic Effect in the Infrared Region by Germanium Quantum Dots Inserted in the Intrinsic Region of a Silicon p-i-n Diode with Nanostructure"

H. M. Tawancy

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Abstract It is the objective of this letter to respond to the comments on the paper entitled "Enhancing the Photovoltaic Effect in the Infrared Region by Germanium Quantum Dots Inserted in the Intrinsic Region of a Si p-i-n Diode with Nanostructure". Evidence is presented to show that the comments are unfounded and contrary to the truth. Although the authors were funded to carry out specific research, they provided some data taken from their already published work.

The objective of this letter is to respond to the comments made by the authors of reference [1] on the paper of reference [2]. However, it is first important to briefly outline the background of the issue raised by their comments.

Because of the recognized expertise of the authors in the area of epitaxial growth as indicated in their comments, they were approached to grow various multilayer structures of Ge/Si and SiGe/Ge with certain specifications for solar cell applications. A service quotation was requested and accepted with a total value of 145,000 Euros divided into separate tasks each with its own cost. The first task costing 34,750 Euros with the objective of determining the photovoltaic response of Ge quantum dots in the infrared region of the solar spectrum consisted of two items: (i) growth of multilayer structures of Ge quantum dots buried in Si spacer layers to serve the function of active layers in the intrinsic region of a Si p-i-n diode using the ultra-high-vacuum chemical vapor deposition technique at the University of Paris-Sud and (ii) structural and optical characterization of the active layers [3]. Our emphasis was to address the role of structural quality of the active layer which has been lacking in previous studies leading to some discrepancies about the exact photovoltaic response of Ge quantum dots [4, 5]. It is well known that the quality of such structures is evaluated by two methods: (i) microstructural characterization using scanning electron microscopy (SEM), atomic force microscopy (AFM), and transmission electron microscopy (TEM) and (ii) optical characterization using photoluminescence spectroscopy (PL). As per the purchase order [3], the above study was to be completed and samples delivered within a period of 6 months ending on September 28, 2009. A 20% down payment was made at the outset and the balance was to be paid upon completion of the work and delivery of the samples. However, the study was not completed until May 2010 and at that time the balance was paid in full. My response to their comments is as follows.

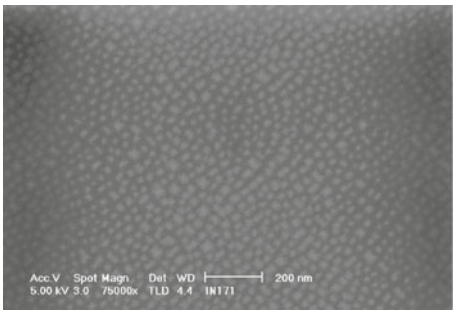
Initially, a two-page report labeled "Preliminary Report" was received from the authors. A portion of that report is shown Fig. 1 and contains the three-dimensional (3D) AFM image, which they claimed that it was copied from their earlier study and then modified. Also shown in the figure is SEM image and both were derived from the structure grown at 550 °C but at different pressures as indicated in their own caption. At a later stage, I received another two-page report labeled "Report Task I.2". Figure 2 shows a copy of Figure 1 of their report, which contains three SEM images derived from the structures grown at 650, 600, 550 °C, and a 2D AFM image. Viewing the images shown in Figs. 1 and 2, it becomes clear that the magnifications of the SEM image and 3D AFM image of Fig. 1 are inconsistent. Also, the magnifications of the 3D

H. M. Tawancy (✉)
Center for Engineering Research and Center of Research Excellence in Corrosion, Research Institute, King Fahd University of Petroleum and Minerals, KFUPM, P.O. Box 1639, Dhahran 31261, Saudi Arabia
e-mail: tawancy@kfupm.edu.sa

Fig. 1 A portion of the preliminary report received from the authors showing Figure 2 of their report

Preliminary report

The density of self assembled Ge quantum dots (QD) is mainly governed by the growth kinetics. Typically, increasing the germane pressure from $5x10^{-4}$ to $5x10^{-2}$ around 550-600°C induces densities values ranging from 10^{9} to $10^{11}cm^{-2}$. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) images of Ge QD performed at 550°C are displayed in Figure 2.

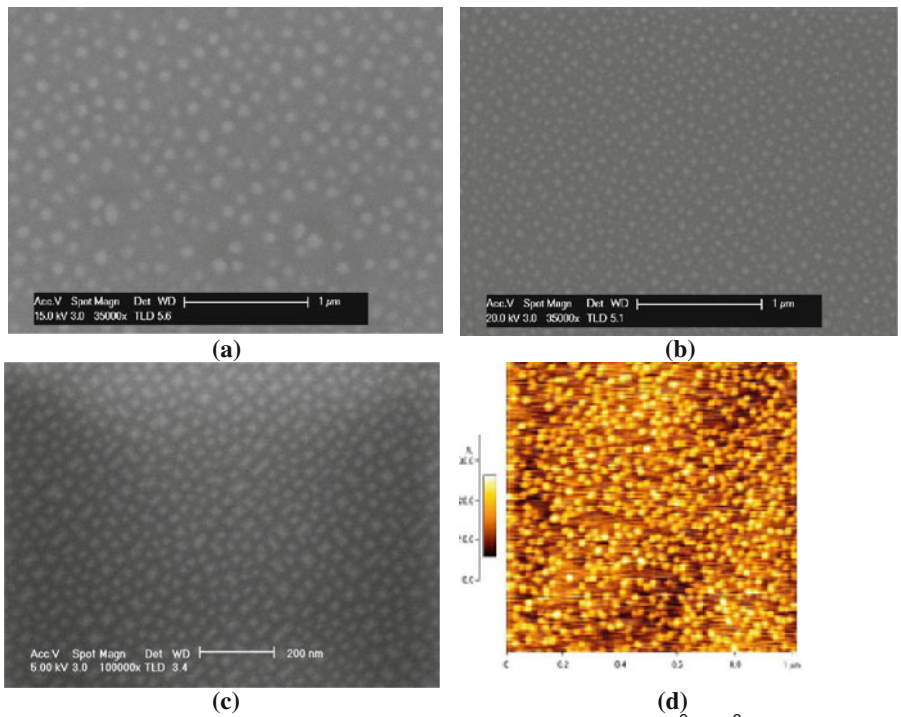


(a) (b)

Figure 2: (a) SEM top view image of Ge QD, with a density of $6.5x10^{10}$ cm^{-2}, with germane pressure of $3x10^{-3}$ Torr and a growth temperature of 550°C. (b) AFM image of dome shaped Ge dots with germane pressure of $2x10^{-4}$ Torr @ 550°C, and a density of $3x10^{9}$ cm^{-2}.

Fig. 2 A portion of Task I.2 report received from the authors showing Figure 1 of their report

Report Task I.2



(a) (b)

(c) (d)

Figure 1: SEM top view image of Ge QD, with a density of $4x10^{9}$ cm^{-2}, with germane pressure of $4x10^{-3}$ Torr and a growth temperature of 650°C (a). SEM top view image of Ge QD, with a density of $1.5x10^{10}$ cm^{-2}, with germane pressure of $7x10^{-3}$ Torr and a growth temperature of 600°C (b). SEM top view image (c) and AFM image (d), of Ge QD with a density of $6.5x10^{10}$ cm^{-2}, with germane pressure of $3x10^{-3}$ Torr and a growth temperature of 550°C.

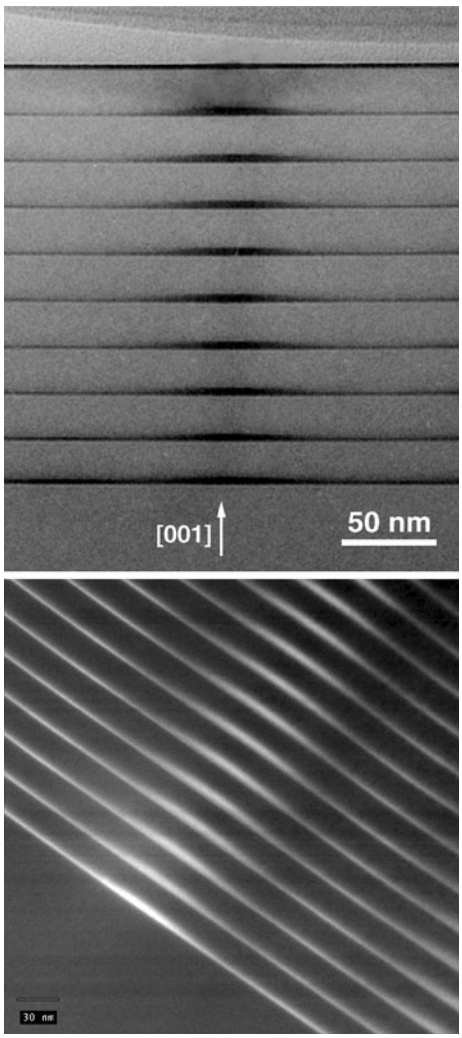


Fig. 3 The two TEM images received from the authors

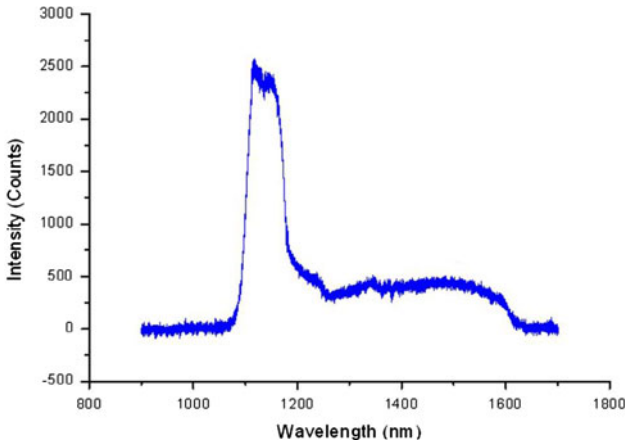


Fig. 4 The initial PL spectrum derived at room temperature and sent by the authors, the highly diffuse nature of the peaks is noted, which makes it difficult to analyze as explained in Ref. [6]

AFM image in Fig. 1 and 2D image in Fig. 2 are inconsistent. Therefore, Professor Aboelfotoh was contacted to clarify this point and whether this could be related to the difference in pressure shown in the caption of Fig. 1. However, he indicated that the respective data was derived from the same structure grown at 550 °C at the same pressure as noted in Ref. [2] and that there has been an error in labeling the data and therefore, the magnification of the 3D AFM image must be adjusted to be consistent with that of the SEM image of Figure 2a of their first report (Fig. 1 in this letter) and the 2D AFM image of Figure 1d of their second report (Fig. 2 in this letter). The three SEM images are shown in Figure 3a of Ref. [2] and the AFM images are shown in Figure 5 of Ref. [2]. It is then evident that no AFM images were copied from their earlier study as they have claimed. In contrast, they have obviously intermixed new data (SEM images) and old data (AFM images) and presented all to me in a report as data derived from the funded research. The same scenario was encountered in the case of the TEM images, which were sent to me. Figure 3 shows the two images as they were sent to me. Portions of these image vertically aligned are shown in Figure 7 of Ref. [2]. Once again, their claim that these images were copied from their earlier study is false. Again, the same scenario was repeated with the PL spectra as described below.

It is well known that PL spectra are used to probe defects in the band gap of semiconductors. As the authors stated, they initially sent me a single spectrum derived at room temperature, which is shown in Fig. 4. However, spectra derived at relatively high temperatures have extremely poor quality and can not be analyzed because the peaks are much diffused [6]. Typically, such spectra must be derived at very low temperature to obtain sharp peaks. After indicating them that the spectrum shown in Fig. 4 is unacceptable, they sent the spectra shown in Figures 3b and 6 of Ref. [2]. As a note added in proof, it is acknowledged in Ref. [2] that the structures were grown by them not by me and that the data claimed to be copied from their earlier study was interpreted in such manner to show that structures were of high quality. In other words, the data was not used to give myself credit which I do not deserve. In the meantime, why copy data from their earlier study while supposedly they should have provided me with a new set of data derived from funded research.

Regarding the comment made about the efficiency and that it can not be realistic based upon their own assumption using results reported in Ref. [7] of their comments, it is apparent that the authors have overlooked the fact that in this case the structure was grown by molecular beam epitaxy, which is known to produce structures of lower quality in comparison with ultra-high-vacuum chemical vapor

deposition [7, 8]. Also, the work reported in Ref. [7] of their comments did not address the quality of the structure used in the study. Therefore, it is not surprising that higher conversion efficiency can be realized from smaller number of Ge/Si layers with higher structural quality (very low defect density).

In conclusion, it is reiterated that no data was copied and/or altered from the author's previous study in any shape or form and that no ethical rules have been violated as falsely claimed by them. Contrary to their claims, the authors have deceived the proponent by intermixing already published data with some new data and presenting all as new data derived from separately funded research.

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