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An Analysis of Electron Transport in Surface-Passivated Nanocrystalline Porous Silicon

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1. Introduction

As a quantum-sized Si nanocrystalline system, porous silicon (PS) exhibits various novel properties: The functions can rearrange various physical limitations of nonconfined-scale single crystalline Si (c-Si).

We reported previously that in nanocrystalline porous silicon (nc-PS) diodes ballistic electrons are efficiently generated under a high electric field [1]. This effect is also observed in the PS diodes formed on polycrystalline silicon (poly-Si) films [2]. The hypothesis of ballistic electron generation has been supported by our experimental (measurements of the energy distribution of electrons emitted from nc-PS diode and measurements of the transient photocurrent decay based on a time-of-flight (TOF) method [3]) and theoretical (a Monte-Carlo simulation of electron transport) analyses [1,4].

According to these experimental results, there is a possibility that injected electrons into nc-PS layer are accelerated by multiple-tunneling through the interfacial barriers between interconnected silicon nanocrystallites and become hot and ballistic. In this report, we investigate the electron drift process in the nc-PS layer to provide a further evidence for the ballistic transport model. To reduce possible interfacial scattering losses, the nc-Si surfaces are passivated with covalent bonds using a chemical functionalization technique.

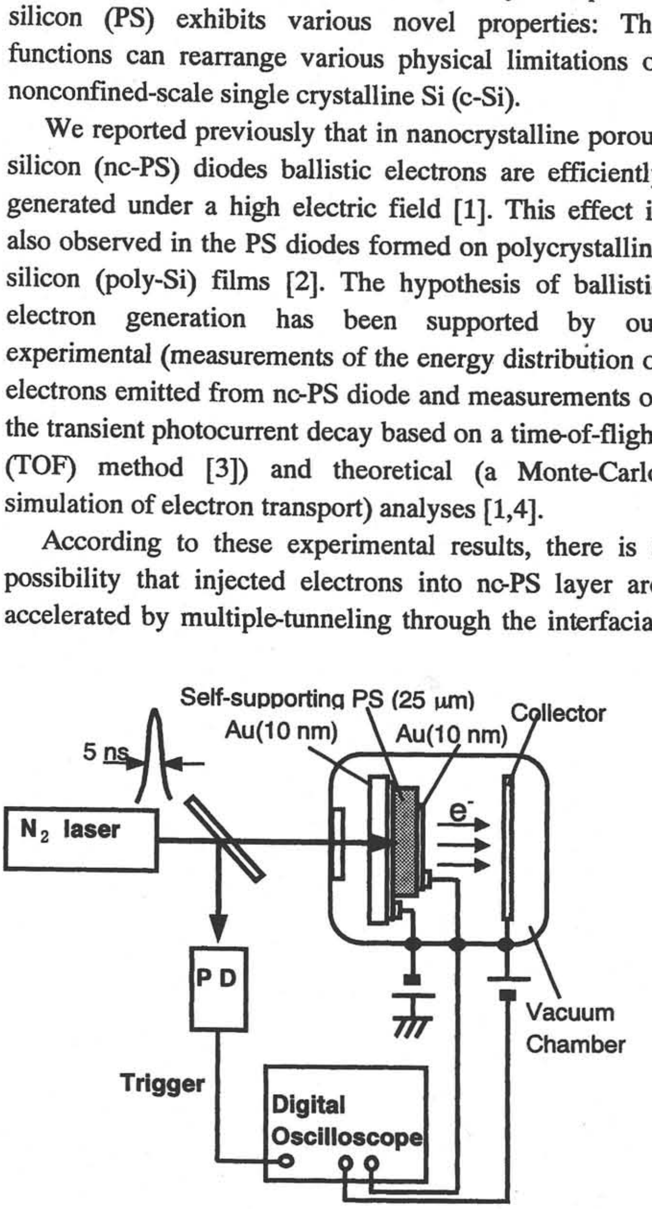

Fig. 1 Experimental setup for TOF measurement. A UV light pulse (337 nm in wavelength 5 ns in dulation) was used for excitation.

2. Experimental detail

Experimental self-supporting nc-PS layer was formed by anodizing single crystalline p-type Si wafer (100) 0.1-0.5 Ωcm with an ohmic back contact in a solution of HF (55 wt%) : ethanol = 1:1. The anodization current was gradually increased (0-100 mA/cm^2 for 2.5 min) with a periodic modulation. Based on the previously reported porosity-multilayer technique, the nc-PS layer has a graded band structure [2]. The thickness of the prepared nc-PS layer is 25 ì m. After anodization, the self-supporting nc-PS film was immersed in 1-decene (CH_2:$CH(CH_2)_7CH_3$) for 1 hr at 95 °C. After this treatment, the residual Si-H bonds in partially oxidized nc-PS layer are replaced by covalent Si-C bonds [5]. The prepared nc-Si film was placed on the surface of the quartz glass substrate coated with Au thin film (10 nm thick). This Au film acts as a back electrode of the sample. Finally, a thin Au film (10 nm thick) was deposited onto the nc-PS layer as a top electrode.

To investigate the effects of modification with organic monolayers, we measured first the induced stationary photocurrent and photoemission under a biased condition. The samples were mounted in vacuum chamber (10^{-7} Torr). A dc bias voltage was applied to the back electrode on the illumination side with respect to the top electrode. We used a 325 nm He-Cd laser for excitation. Next, we used a TOF technique as shown in **Fig. 1** for characterization of the electron transport process in the nc-PS layer. The nc-Si sample was mounted in vacuum chamber (10^{-7} Torr). Electrons were photogenerated in close proximity to the back electrode by a UV light pulse (5 ns width nitrogen laser with a wavelength of 337 nm). The transient curves of photocurrent and photoemission were observed with a digital osilloscope.

3.Results and discussion

Figure 2 shows the photocurrent I_{PH} and the photemission I_e vs applied voltage V_{PS} for the as-anodized

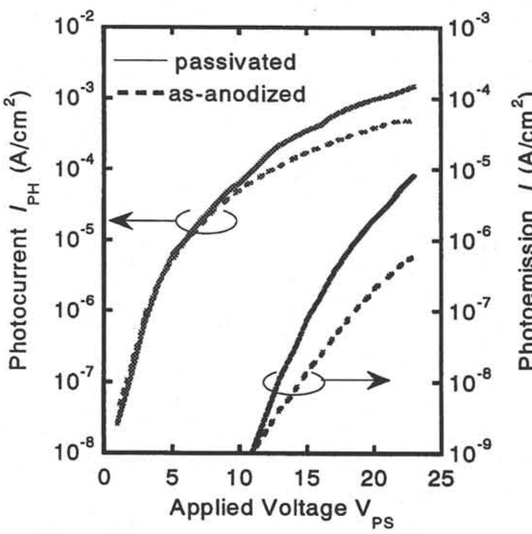

Fig. 2 Photocurrent and photoemission dencities vs applied voltage for as-anodized and passivated sample.

sample and the passivated sample. The values of I_e and efficiency of electron emission η at V_{PS} = 23 V for the passivated sample is 3 times and 4 times larger than that of the as-anodized sample. The F-N plots obtained from the data of **Fig. 2** are shown in **Fig. 3**. The observed

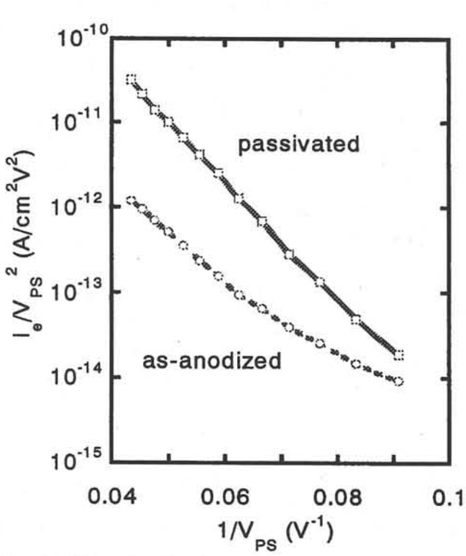

Fig. 3 The F-N plots for the photoemission originated from Fig.2

linear relationship of the F-N plots for the passivated sample indicates that field-induced tunneling process occurs in a wide range. In contrast, the plots for the as-anodized sample show a linear relationship only in a small region. These experimental results show that the multiple-tunneling effect is enhanced, whereas the thermally assisted transport is significantly suppressed.

The transient photocurrent curves for two samples show an exponential decay. The behavior is different from that of amorphous silicon such as multi-trapping and re-excitation by the thermal effect Also, the result is completely different from that of crystalline silicon in which electrons tend to be thermalized at the bottom of the conduction band due to a serial scattering process.

The apparent difference between the two samples appears in the dynamic behavior of the photoemission current. The following two results have been obtained: (1) the observed response curves of the photoemission show the pulse-shaped signals, (2) the rise time of the response is shortened by the surface passivation of nc-Si particles.

The observed quick response of the photoemission in the passivated sample suggests that the quasiballistic electrons with higher energies are efficiently generated at a very short time after light pulse incidence.

4.Conclusion

It has been shown that the field-induced transport in the nc-Si layer is enhanced by the surface passivation of nc-Si particles. The modification of nc-PS surfaces with the covalent Si-C bonds. enlarges the average drift length of electrons between traps. The result supports the ballistic model that the interface of interconnected nc-PS is key issue for tunneling cascade.

References

[1] N.Koshida, X.Sheng and T. Komoda: Appl. Surf. Sci. **146** (1999) 371.
[2] X. Sheng and N. Koshida, Mat. Res. Soc. Symp. Proc. **509**, 193 (1998). (2000) p. 14.
[3] A. Kojima avnd N. Koshida, Phys. Status Solidi (A) (2002) (in prvess).
[4] A. Kojima and N. Koshida, Jpn. J. Appl. Phys. **40**, 2779 (2001).
[5] R. Boukherroub, S. Morin, D. D. M. Wayner, F. Bensebaa, G. I. Sproule, J.-M. Baribeau, and D. J. Lockwood, Chem. Mater. **13**, 2002 (2001).