Synchronization on source layer makes interlayers connections more sensitive to information transfer

Pachaya Sailamul and Se-Bum Paik

*Department of Bio&Brain Engineering, KAIST, Daejeon 305-701*

Correlate neural activities, such as oscillation and synchronization are one of the important keys for communication in the brain. However, the question on how to modulate the synchronization level and how these synchronized activity affect spike transfer from one layer to another layer in different convergent connection conditions are not clearly understood. In this paper, we employ computer simulation of realistic neural network to address the question.

The neural network consists of two layers of conductance based single cell model, source layer and target layer. The interlayer connection follow statistical wiring diagram, for which, strength and connectivity of the connection depend on the distance between the target cell when projected on source layer and the source cells. For controlling, we built two other connection methods while fixed constant connectivity. One is the constant strength of connection and another the random strength of connection that follow negative exponential distribution. The response function of the neural network was measured with various pattern of input to the source layer. Then, the level of spike transfer from one layer to another was measured from various conditions. To study how one specific type of ions channel controls level of synchronization in the network, we conduct the experiment when T-type calcium channel functions and when it is not.

We showed that synchronization facilitates spike transfer between neuronal layers. We compared level of spike transfer in the controlled neural network system with independent input spike trains and the neural network with oscillating input. We found that when the synchronization between inputs to the system is high, the spike information can transfer to target network with less convergent connection.

In summary, we found that neural network could selectively allow the information from specific synchronization level to be transfer to another layer. And this level of synchronization in the network can be modulated by T-type calcium channel. This paper suggested more study on the potential of T-type calcium channel and level of synchronization as the key to understand information transfer in the brain.

*PACS number: 42.30.R, 42.40.Ht, 42.30.Kq <?>*

Keywords: synchronization, neural network, modeling

Email: jkps@kps.or.kr <//>

Fax: +82-2-554-1643 <//>

I. INTRODUCTION

Correlate neural activities, such as oscillation and synchronization are one of the important keys for communication in the brain.

In this paper, we showed that synchronization facilitates spike transfer between neuronal layers. We compared level of spike transfer in the controlled neural network system with independent input spike trains and the neural network with oscillating input. We found that when the synchronization between input to the system is high

Adsorption of molecules on surfaces has been a subject of great interest. Many molecules goes through a weakly bound trapping-mediated state before more stable chemisorption takes place. The kinetics of such trapping-mediated adsorption has long been studied theoretically and experimentally, particularly on metal surfaces [1-4]. On the other hand, on technologically important Si surfaces, similar studies of the kinetics in chemisorption are very scarce. The temperature-dependent decay of the precursor state was reported for oxygen adsorption on the Si(111)-7×7 surface [5, 6], but the nature of the complex oxidation process is still ambiguous [7-9]. Stimulated by recent technological advances in applications to organic thin film devices [10,11], adsorption of ethylene on Si(001) was studied as a prototype reaction of olefinic molecules on silicon surfaces [12]. This class of molecules commonly shares the chemisorption structure of a molecular adsorbate bonding to a Si dimer through stable di-σ Si-C bonds through the so called [2+2] cycloaddition reaction [7,13,14]. The chemisorption of ethylene (*C*2*H*4) molecules on Si(001) via a mobile precursor state was first suggested using a molecular uptake method [15], while its existence at the early stage of chemisorption was questioned in photoemission [16]. Recently, three-membered π-complex precursor structures were proposed by density functional calculations [14,17] similar to those of acetylene [18,19], and stable intermediate states found in electron energy loss spectroscopy at 48 K were attributed to the feature [20]. However, still lacking is firm evidence for the existence of the intrinsic mobile precursors, as well as the decay kinetic information to shed light on the gas-surface reaction dynamics on Si surfaces.

In the present paper, we report on the investigation of trapping-mediated chemisorption of ethylene molecules on the Si(001)-c(4 ×2) surface at low temperature using a scanning tunneling microscope (STM), an ideal tool to detect minute atomic-scale changes on the surface. By observing the decay of trapped molecules in thermal equilibrium with the surface and employing a method minimizing the tip-surface interaction, we examined the decay kinetics of the trapped molecules. The results paint quite a surprising picture of the trap state as well as its decay kinetics dominated by entropy.

II. EXPERIMENTS AND DISCUSSION

Experiments were performed using a low-temperature STM (Omicron GmbH) with the base pressure below 3*:*0 *×* 10-11 mbar, equipped with double cryoshields and a resistive heater mounted on the STM head. The preparation of a clean Si(001)-c(4 *×* 2) surface (n-type, 3 Ω­cm) with a defect density *<* 0.1 % was described elsewhere [21]. Weakly bound molecular states on the surface was prepared by introducing ethylene on a Si(001)-c(4 *×* 2) surface at the substrate temperature of 50 K and 80 K by back-filling the chamber at a pressure of 2 *×* 10-8 mbar, monitored by a quadruple mass spectrometer. After the base pressure was restored, images were taken without an additional dose. All STM images were obtained at the tunneling current of 10 pA, and the sample bias of -1.5 V.

This shows a typical STM image of a Si(001) surface exposed to ethylene molecules of 5.5 L at 80 K. Upon the exposure, only a single type of features, a slight depression on a Si dimer site, was observed. Each slightly depressed feature represents a chemisorbed ethylene in a 'di-σ' structure, in which the C-C bond is parallel to the Si dimer bond and two σbonds between C and Si atoms are formed, as represented by ball models. This is consistent with the theoretical prediction [14] and the previous STM results at room temperature [7,13]. On the other hand, no feature attributable to trapped species was observed. Chemisorption sites were randomly distributed over the Si(001)-c(4*×*2) surface, even on neighboring dimmer sites along the same dimer row. The surface was completely saturated by chemisorption sites at more than 10 L of the total ethylene dose (images not shown here). On the other hand, a strikingly different adsorption behavior was observed at 50 K on the same amount of ethylene dose. The number of initial chemisorbed sites was drastically less than that produced by the identical dose at 80 K. Despite the huge disparity in the chemisorption coverage, however, no difference was found between chemisorbed sites produced at these two temperatures, indicating they are in fact identical. This was also checked by annealing the surface to 80 K and higher. As the temperature was slowly raised from 50 K, the number of reacted sites increased and approached an asymptote by 110 K annealing, where there occurred no further chemisorption events. This suggests that adsorbed ethylene molecules are held in a weakly bound trap state on the Si(001) surface at 50 K, although invisible to STM, and decay slowly to a more stable chemisorption state. Decay persisted over a few days at the substrate temperature of 80 K. In order to understand the kinetics in trapping-mediated chemisorption of ethylene molecules, we investigated decay to the chemisorbed state at several substrate temperatures. We first introduced ethylene molecules of 6 L on a clean Si(001) surface at 50 K, and subsequently raised the substrate temperature to the desired value for the decay measurement. While maintaining the temperature within 0.5 K, we were able to obtain large scale STM images for a few days consecutively. To avoid the tip-induced effect, a special care was strenuously exercised. Not only all images were obtained at a low tunneling current of 10 pA, but also each image was acquired at a fresh new location. The possibility of tip effects on the decay rate was monitored by taking a few consecutive images over an area, followed by the inspection of an inclusive, zoomed-out large area; Any difference between the inner area scanned over repetitively and the fresh outer area would be indicative of the tip-adsorbate interactions. No such difference was found, indicating that the tip effect is negligible. In addition, our method of moving to a fresh location for each image acquisition would cause any tip-effects turn up as a constant shift in the background, which can easily be subtracted later.

III. CONCLUSION

In conclusion, the chemisorption of ethylene molecules on Si(001) was investigated using STM at low temperature. Ethylene molecules first adsorbed in a trap state decay to a chemisorbed state through a thermally activated process exhibiting Arrhenius behavior with an anomalously low PEF. The origin of the suppression in the PEF is attributed to the entropic bottleneck at the transition state caused by free-molecule-like trap states. The existence of a long-lived trapped species and the simple chemisorption process makes ethylene an ideal molecule to study trapping-mediated adsorption on Si surfaces, thereby providing a fascinating view into the gas-surface reaction dynamics at low temperature.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Kim for helpful discussions and gratefully acknowledge support by MOCIE through National R&D Project for Nano Science and Technology. C.H.C. and W.J.J. acknowledge the financial support by MOE through BK21 fellowships.

REFERENCES

[1] G. D. Hong and Y. S. Chang, J. Korean Phys. Soc. **45**, 1000 (2004).

[2] J. F. Weaver, A. F. Carlsson and R. J. Madix, Surf. Sci. Rep. **50**, 107 (2003).

[3] Y. G. Ptushinskii, Low Temp. Phys. **30**, 1 (2004).

[4] R. I. Masel, *Principles of Adsorption and Reaction on Solid Surfaces* (Wiley, New York, 1996).

[5] U. Höfer, P. Morgen, W. Wurth and E. Umbach, Phys. Rev. Lett. **55**, 2979 (1985).

[6] C. Silvestre and M. Shayegan, Phys. Rev. B **37**, 10432 (1988).

[7] A. Mayne *et al.*, Surf. Sci. **284**, 247 (1993).

[8] H. Okuyama, T. Aruga and M. Nishijima, Phys. Rev. Lett. **91**, 256102 (2003).

[9] K. Sakamoto, H. M. Zhang and R. I. G. Uhrberg, Phys. Rev. B **70**, 35301 (2004).

[10] R. A. Wolkow, Annu. Rev. Phys. Chem. **50**, 413 (1999), and references therein.

[11] S. F. Bent, Surf. Sci. **500**, 879 (2002).

[12] R. Konecny and D. J. Doren, Surf. Sci. **417**, 169 (1998).

Table 1. Base pressure before and after injecting hot oxygen into the foreline of the TMP with magnetic bearings.

|  |  |  |  |
| --- | --- | --- | --- |
| P(Torr) | Pback  (Torr) | Backing  Pump | Chamber  Bakeout |
| 1.0×10-11 | 9.6×10-8 | TMP  (55ℓs-1) | 200 oC, 48 h |
| 7×10-12  (with O2 Injection) | 1st stage | TMP  45 ℓs-1 (H2 )  K=104 | 130 oC, 36 h |
| 5×10-12  (with O2 Injection) | 2nd stage  1.1×10-5 | TMP  (55ℓs-1) | 130 oC, 36 h |

Figure Captions.

Fig. 1. If figures cannot be included within the Word file, they may be uploaded in separate files.

See details in the journal home page, http://jkps.kps.or.kr/.

Fig. 2. If figures cannot be included within the Word file, they may be uploaded in separate files.

See details in the journal home page, http://jkps.kps.or.kr/.