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Future prospects of nanometer functional devices

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Regular arrays of microclusters are fabricated on the surface of graphite and silicon to investigate possiblities for a new type of nanometer functional devices. The result demonstrates that they can be used as ultra-high density memories and switching elements.

1. INTRODUCTION

Ever since the experimental findings of microclusters with their magic numbers on structural stability and the subsequent discovery of fullerenes and other exotic small particles[1], there have been many investigations towards the possibilities of realizing nanometer scale devices for processing electrical and opto-electronic signals. Some of them has succeeded in registering the transfer displacement of a single electron across the surface barrier of a cluster[2]. The modification of these principles, however, has to meet considerable degree of technical difficulties, if we consider the thermal noise level and the mechanical precision required for fabricating practical devices on the mass-production basis. This paper presents our proposal[3,4] on several kinds of new principles which could be modified to a novel memory or switching element in an intermolecular scales of 10 nm or less.

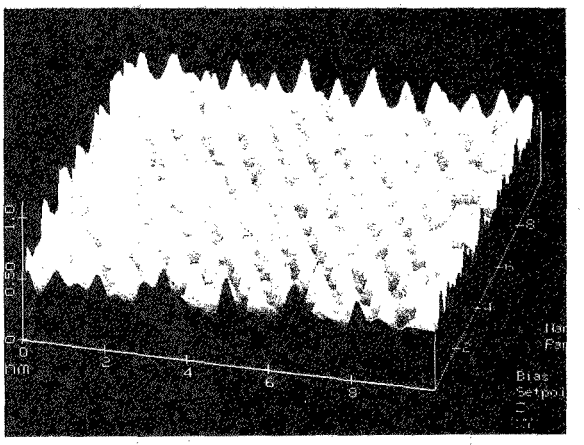

Figure 1. Topological STM image of Se rings on graphite surface at a bias voltage of +150mV.

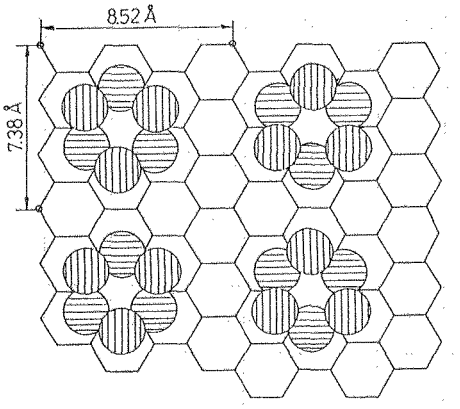

Figure 2. Schematics of Se_6 rings aligned on the c-plane of Graphite.

2. READ-ONLY-MEMORY OF Se_6 ON GRAPHITE

Selenium molecules have at least four kinds of allotropic structures to our knowledge, namely Se_6,

allotropic structures to our knowledge, namely Se_6, Se_7, and Se_8 of ring structures[5] and those of spiral chains of three fold symmetry. One may extract and evaporate from their organic solvent only the ring component on the surface of highly-oriented pyrolitic graphite (HOPG). As it may be recognized from the STM image of Fig. 1 with its geometrical illustration of Fig. 2, we have been able to arrange Se_6 molecules in commensurate with the hexagonal surface of graphite by 3 to 1 ratio. This arrangement can be maintained as far as the potential of Se-ring is kept at approximately -65mV or higher (towards +) with respect to the STM probe of tungsten[3]. If the ring molecule is placed at a lower (more negative) potential, the arrangement becomes at random as shown in Fig. 3, and eventually transforms into a macro-molecular aggregates as in Fig. 4 at a bias potential of about -700mV. These changes in the two dimensional arrangement may be confirmed by our auto-correlation analysis of periodicity in both regular and random arrangements.

If these two types of ring molecular arrangement can be used as a binary memory, it may be stored on a graphite surface area of 10nm x 3 nm, which may be read over a scanning period less than 10 μsec.

3. REVERSIBLE AND MULTI-VALUED MEMORY OF C_{60} ON Si

The previous memory element of Se-ring may be useful only within a certain range of bias potential, and can not be erased nor reversed. To compensate for this non-flexibility, we show another example of using an s-p hybridized electronic orbit in C_{60} ad-molecules on a multilayered C_{60} film. Several monolayers of C_{60} were evaporated on a Si(111) surface as shown in Fig. 5. Upon light irradiation by 514.5 nm line of Ar-laser at 10 W/cm^2, the STM

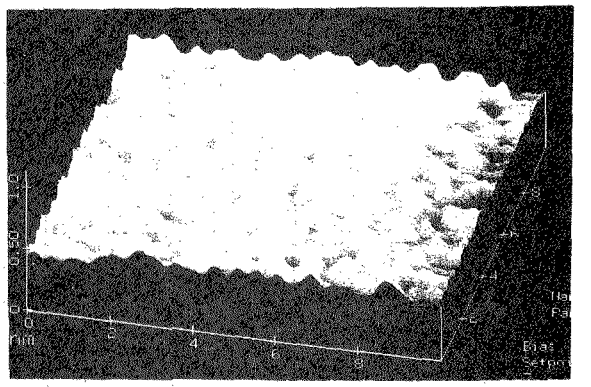

Figure 3. Topological STM image of Se rings on graphite surface at a bias voltage of -150mV.

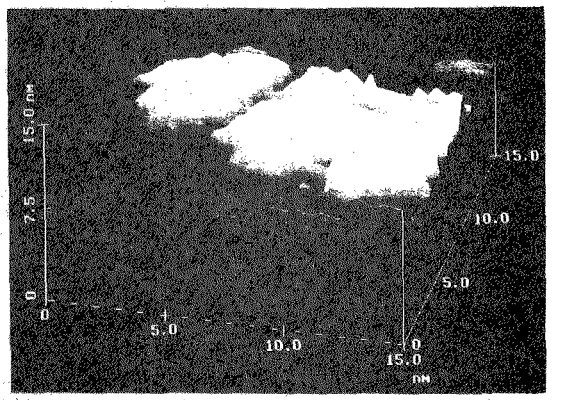

Figure 4. Topological STM image of Se rings on graphite surface at a bias voltage of -750mV.

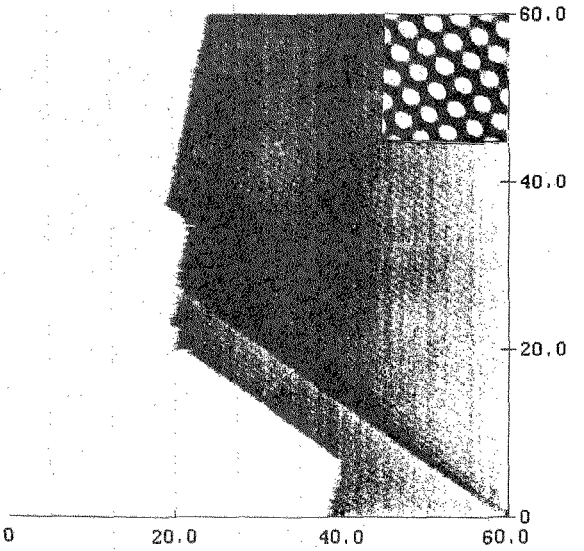

Figure 5. STM image of C_{60} on Si(111) surface at a bias voltage of 3V.

probe exhibits various patterns of local electronic states as shown in Figs. 6. This particular electronic structure has been calculated by a supercomputer by the groups of Gu[6] and of Kawazoe et al.[7]. Since the intermolecular interactions are mainly of the van der Waals type, their calculated results give a good reference to understand our observed pattern of electronic orbit at various energy levels. Since we find three types of local electronic structure in Fig. 6, we may assign ternary memories for a single molecule of C_{60}. Fig. 7 shows another example of patterns.

4. SUMMARY AND FUTURE PROBLEMS

Our experimental results show that the arrangement of microclusters can be controlled by external fields and exhibits various electronic functions in nanometer scale. Our key technical problem in a practical application is to ascertain the nanometer precision of positioning the STM probe at each microcluster arranged on a surface area of macroscopic scale. Our investigation shows that this technical difficulty is overcome, for example, by using a so-called "Beetles" type STM[8] in which the sample surface can be scanned a distance over 5 mm in any direction by three piezo-electric supporting rods, while the STM tip is kept engaged to monitor its location on the surface by the tunneling current. The rest of the technical problem is to improve the reading speed which is less than 1 μm /1μs at present.

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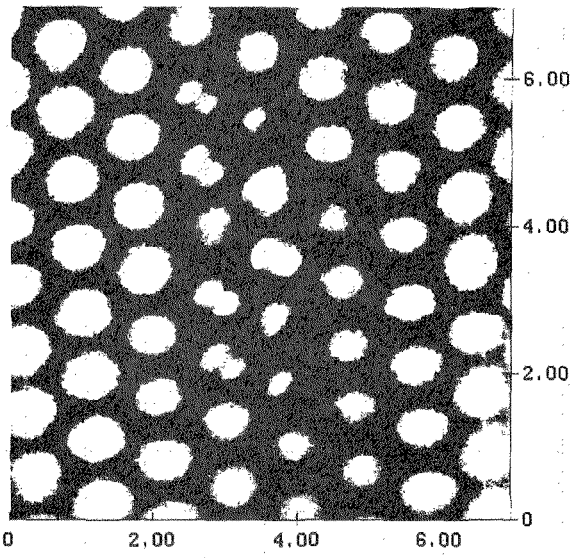

Figure 6. STM image of C_{60} on Si(111) surface at a bias voltage of 3V after Ar laser irradiation at 514.5 nm for 10 min. at 10W/cm^2.

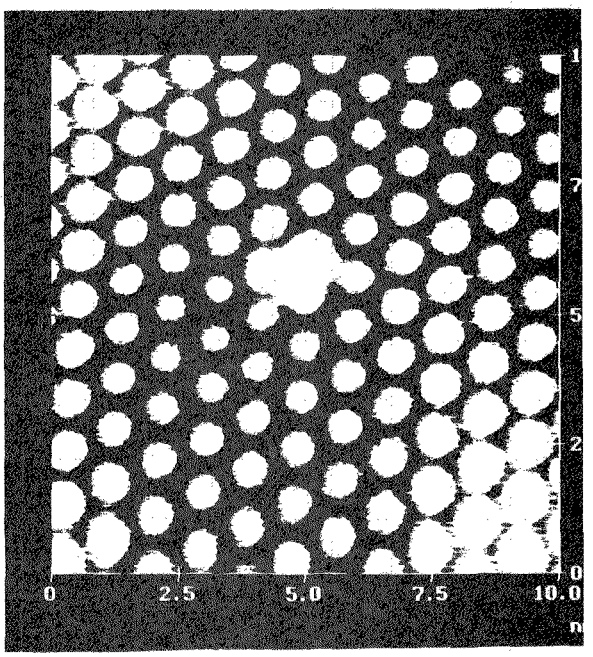

Figure 7. STM image of C_{60} on Si(111) surface at bias voltage of 3V after Ar laser irradiation at 514.5 nm for 10 min. at 12W/cm^2.

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