Development of an Instrument for Surface Conductivity Measurements at μm Scale Region in Ultra High Vacuum

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Abstract

We have developed a new measurement system (Fig. 1) in ultra high vacuum (UHV) which consists of three tips, and is going to be extended to four tips, and each of these tips is controlled by a three axis inertial drive. This system is combined with a JEOL UHV scanning electron microscope (SEM) which is able to observe four tips for precise positioning. This system is designed to measure surface conductance or dc-conductance of surface nano-structures by the four terminal method at a μm or sub-μm scale through manipulating these four probes.

Introduction

The surface electrical conductivity on atomically ordered surfaces has not been studied until recently. However, several works using four point probe conductance its measurements have been done on, for example, 5x2-Au on Si (111), $\sqrt{3}$x $\sqrt{3}$-Ag on Si (111)[1], clean 7x7 Si (111) and oxidized Si (111)[2] surfaces. The probes for the conductivity measurements are separeted by

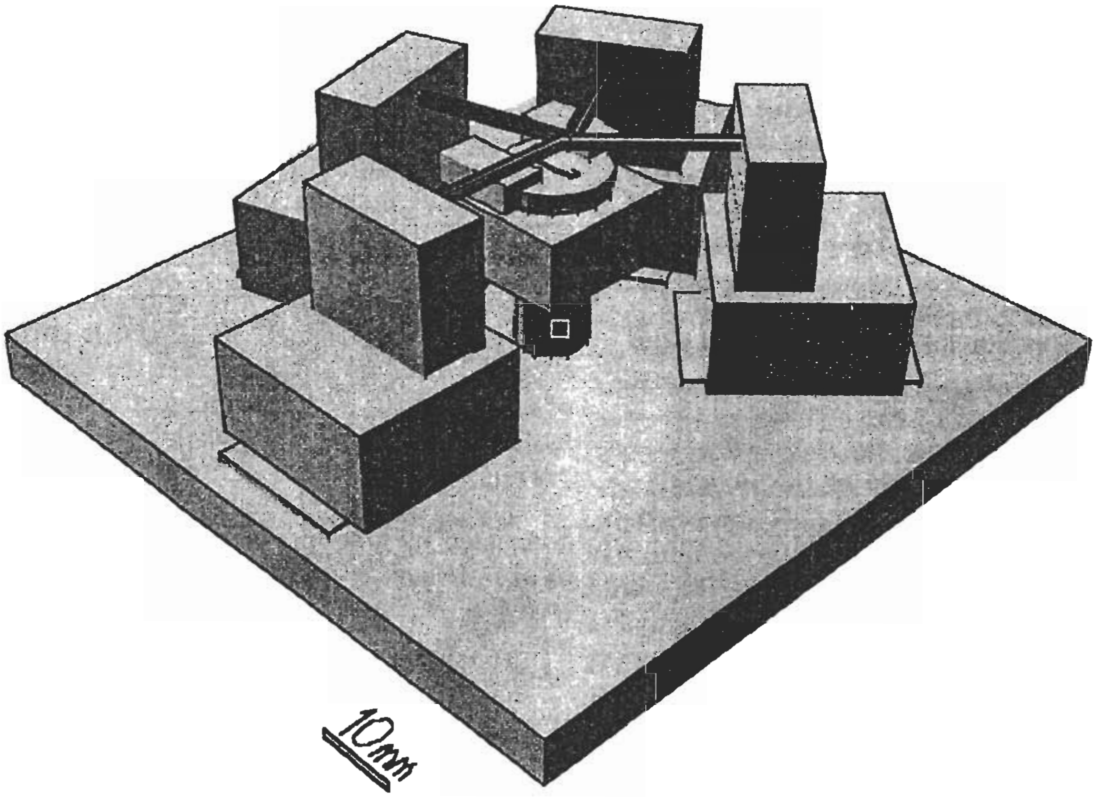

Fig.1 Drawing of the instrument. There are four independent three axis inertia drives on a base plate which is supported by a rod from UHV flange.

the order of mm scale in these works.

The surface conductance via surface states is generally thought to be very sensitive to the scatterers on surfaces such as atomic steps. To avoid this effect, one should measure surface conductances within very small area, for example, within one atomically flat terrace. In order to realize measurements on this small-area, we have developed an instrument with three movable probes and SEM, and is able to extended to four tips system.

Design of the Instrument

Basic specifications for our instrument are as follows. First, four probes are needed to realize the four point dc-measurement at μm-scale region. Second, the positions of these four probes should be controlled with resolution of around 10 nm. And last, it's better that whole instrument can be cooled down to very low temperature in order to freeze careers inside substrate, for example, silicon.

To meet this requrements, we selected the three-axis inertial drive[3] as a tip positioner with precision down to nm region. The inertial drive for each axis consists of three stainless steel balls and sapphire V-grooves in which these balls slide. These stainless steel balls are glued onto stack piezo which produces stick-and-slip motion. Since contacts between balls and V-grooves are point contacts, one should select soft material for balls and hard material for grooves, otherwise it has been found that scratches are easily formed on the surface of the V-grooves.

Four tips must be very closely placed (~1μm) each other. For that purpose, we have to use tungsten tips because its sharp shape is more desirable than reported[4] shape of platinum tips. The angle between tip-axis and sample surface is 45 degree to avoid touching of each tip to the others. For electro-chemical etching of the tungsten tips, immersion length should be increased during the etching process to get tips with high length-to-diameter ratio (Fig. 2).

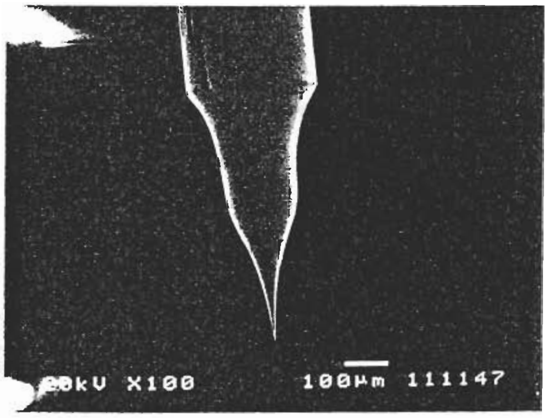

Fig.2 An SEM photo of a tungsten tip which has been made in order to avoid touching eachother in the 4-probes system. See text.

Our instrument also has the scanning tunneling microscope (STM) function. To realize this function, we placed a tube piezo scanner which has a scanning range of 1(m which is attached to the bottom-side of the sample-mount. Then one might fabricate nano-structures *in situ* during measurement of dc-electrical character-istics using three probes. If these three probes stick onto substrate, the slight movement of the sample will not make problems. This simul-taneous fabrication-measurement method is desirable for the fabrication of nano-structures that are contaminated easily.

These four probes can be observed by an SEM (JEOL TM-50011 HVSEM) and one can adjust position of these tips during SEM observation. The largest scanning area for the SEM is around 1mm. For coarse alignment of four tips, we use CCD camera which is attached outside the UHV chamber. The lowest pressure for the chamber is around $3x10^{-7}$ Pa so far.

The non-insulating samples are desirable because our instruments includes SEM and STM. When semiconductor such as silicon is used as a substrate, it is necessary to cool samples down to very low temperatures to freeze-out bulk conductivity. For this purpose, copper is used as a material for the base plate of our apparatus which is connected to a small liquid helium tank. Sample is held on a tube piezo scanner that is not a good heat conductor, so sample and the base-plate are connected by a copper ribon. The temperature of sample can be measured by a thermocouple (Au-Fe-Chromel) which is attached to the sample holder on the piezo scanner. Four probes should be cooled by sample because these probes are floated electrically and it is not easy to cool them via electrical insulator. In the preliminary test, the lowest temperature we have got was around 15 K.

Sammary and Outlook

We have developed a UHV three-probes dc-electrical measurement system. It can be extended to four probes system by installing fourth inertial drive. Some functions have been checked such as the fine motion of 3-axis inertial drives under an SEM and the cooling capability down to around 15 K.

By using the instrument which we have developed, we expect that it is possible to measure surface conductances within a small area which contains small number of surface scatterers. Also, we plan to make nanostructures *in situ* on surface by an STM during measuring its electrical properties.

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