Chapter 2

Experimental details

2.1. Ion source

2.1.1. Principle of operation

The ion source used for this thesis experiments is a commercial Sputter Ion Source ISE 10 manufactured by Omicron [1]. Ions with energy ranging from 0 to 5 keV can be produced by the ion source. Ions are generated in a collision chamber of the ion source; thermal electrons, emitted from a circular Y₂O₃ coated ribbon filament (cathode), are accelerated by an anode grid at the potential of +120 V. While traveling to the anode, those electrons ionize neutral particles (in these thesis experiments, Xe atoms) present in the source volume between the cathode and the anode. The anode is specially designed in a way that allows the electrons to cross the source volume many times to raise the number of the collisions between the electrons and the neutral particles; the yield of the initially generated ions \( I^+ \), which depends on the electron emission current \( I_E \) (≤ 10 mA) and the gas pressure inside the ion source \( P_{IS} \), is approximately expressed as [1]

\[
I^+ \cong (4\text{torr}^{-1}) I_E P_{IS}.
\]

(2-1)

The ions are extracted from the source volume by a voltage of about 200 V and accelerated to a variable energy up to 5 keV. Ions with energy higher than 5 keV can be produced by biasing the ground of the ion source with a high voltage power supply; 20 keV Xe ions were produced using a high voltage power supply manufactured by Glassman for the experiments in section 4.2.3. An electrostatic lens, located right behind
the extractor, focuses the ions into a beam. Using adjustable bellows attached to the ion source flange and a phosphor coated glass bonded to a stainless steel sample holder, the ion beam can be aligned to hit the sample.

Xe gas is introduced to the ion source by a leak valve manufactured by Gransville-Philips. The outlet of the regulator, manufactured by Matheson Gas Products, is attached to the bottle of Xe gas of research grade 99.995 % purity, also purchased from Matheson Gas Products, and is set to about 25 psi. The Xe gas remaining between the outlet of the regulator and the leak valve is regularly pumped out before a bakeout of the STM chamber and the ion source. Since this portion of the tubing between the outlet of the regulator and the leak valve is maintained at the pressure of about 25 psi, outgassing from the inside wall of the tubing can be neglected compared to the Xe gas pressure, and therefore this portion does not need to be baked.

2.1.2. Operation of ion source

The ion source needs to be fully baked before operation. Before the bakeout, heating bands are wound around the ion source and gas line tubing down to the leak valve, and those heating bands are wrapped up with aluminum foil. Since there is no gate valve between the ion source and the STM chamber, the ion source and the STM chamber are baked together. More details of baking the STM chamber are discussed in section 2.2.1. After the bakeout, degassing of the ion source filament is done by pressing the Degas button on the ion source power supply, which will trigger the power supply to start increasing the electron emission current gradually to the maximum of 14.4 mA. This
maximum current will be maintained for about 2 minutes and then the electron emission current will turn off automatically.

During the ion source operation, the ion pump equipped with the STM chamber is turned off and the cryopump equipped with the 4-inch intro chamber is pumping the STM chamber, the 4-inch intro chamber and the ion source; I tried using the ion pump during several ion irradiation experiments, but each time the ion-irradiated Ge surfaces showed threading dislocations probably due to carbon contamination created by outgassing from the ion pump. The pressure of the STM chamber reads $3.5 \times 10^{-7}$ torr for most of the keV Xe ion irradiation experiments reported in chapters 3 and 5, and $6.0 \times 10^{-9}$ torr for individual 20 keV Xe ion impact experiments reported in chapter 4.

The angle of incidence of keV Xe ions is fixed at $50^\circ$ from the sample surface normal. The ion current is measured using a 1 inch diameter molybdenum plate current probe attached to a linear motion feedthrough, and Keithley 410 micro-microammeter connected to the current probe. To measure the ion current density, a stainless steel sample holder, which has a small hole in the middle with the diameter of 3 mm, is placed in front of the current probe by the transfer rod equipped with the STM chamber; the ion current flow through the 3 mm hole is measured, and taking the geometry of the hole into account, the ion current density is measured. Since the 3 mm hole is an ellipse from the viewpoint of the incoming ions, considering the thickness of the sample holder, the effective area of the 3 mm hole is $3.1 \times 10^{-2}$ cm$^2$. For the studies on the formation of bulk nanocavities in chapter 3 and the surface roughening of Ge during 5 keV Xe ion etching in chapter 5, the measured current through the 3 mm hole is $5.0 \times 10^{-8}$ A, giving the
current density of 1.6 µA/cm², which corresponds to $1.0 \times 10^{13}$ ions/cm²s. For the studies on the annihilation of bulk nanocavities on Ge surfaces in chapter 4, the measured current through the 3 mm hole is $1.5 \times 10^{-7}$ A, giving the current density of 4.8 µA/cm², which corresponds to $3.1 \times 10^{13}$ ions/cm²s. For the studies on the individual 20 keV Xe ion impact on Ge surfaces in chapter 4, the measured current through the 3 mm hole is $1.2 \times 10^{-9}$ A, giving the current density of 0.040 µA/cm², which corresponds to $2.5 \times 10^{11}$ ions/cm²s.

2.2. Scanning tunneling microscopy (STM)

2.2.1. STM chamber

All the in situ Ge sample preparations and STM experiments are performed at the Epicenter. The Epicenter has six MBE growth chambers and three surface analysis chambers including the STM chamber, which are all interconnected by the four main transfer tubes maintained in ultrahigh vacuum (UHV), i.e. $10^{-10}$ torr range, by ion pumps and cryopumps. An introduction chamber or load lock equipped with a cryopump is attached to each main transfer tube and samples are introduced to the transfer tube via the introduction chamber; before the samples are introduced to the main transfer tube, the introduction chamber is typically pumped by the cryopump for about 12 hours after the samples are loaded.

The STM chamber is connected to the 4 inch intro chamber equipped with a cryopump manufactured by CTI-Cryogenics, and the 4 inch intro chamber is connected to a main transfer tube. Two sample holders can be kept at the 4 inch intro chamber.
There is a gate valve between the main transfer tube and the 4 inch intro chamber, and another between the 4 inch intro chamber and the STM chamber. A typical base pressure of the STM chamber is $1 \times 10^{-10}$ torr and the ion gauge is set to 10 mA emission current to monitor $10^{-10}$ torr pressure range. Except during the ion irradiation experiments, the STM chamber is pumped by a Starcell ion pump, manufactured by Varian, whose pumping speed is 230 liters/s. As mentioned in chapter 2.1.2, when the ion irradiation experiments are done, the Starcell ion pump is turned off and the gate valve between the STM chamber and the 4 inch intro chamber is open. The CTI-Cryogenics cryopump maintains the pressure in the STM chamber, the 4 inch intro chamber and the ion source, while Xe gas is flowing for the ion source to produce keV Xe ions. The pumping speed of the cryopump is as high as 4000 liters/s for water molecules.

The STM chamber has many flanges at which the Starcell ion pump, electrical and linear motion feedthroughs, and view ports are attached. The vibration isolation system, which consists of two sets of 3 springs, is attached to the STM stage, and the springs are mounted on the 8 inch flange, which is placed at the top of the STM chamber. All the wires connecting the STM to the STM controller go through the feedthroughs attached to the 8 inch flange. Also attached to the 8 inch flange is a wobble stick with which one can put the STM on the sample. There are three rubber bellows and a set of stainless steel bellows between the STM chamber and the 4 inch intro chamber to isolate the STM chamber from the noise coming from the cryopumps and the main transfer tubes. The rubber bellows are filled with nitrogen gas to the pressure of about 20 to 30 psi.
To obtain UHV in the STM chamber after venting to air, the STM chamber needs to be baked to desorb the gas molecules, especially water molecules, adsorbed on the inner surface of the STM chamber [2]. After all the flanges are sealed, the STM chamber is pumped down to $< 1 \times 10^{-4}$ torr using a Drytel pump and then the ion pump is turned on. The STM chamber is normally wound around with heating bands, thus after wrapping up the STM chamber with aluminum foil, electric power is applied to the heating bands using variable AC transformers during the bakeout. Parts vulnerable to high temperature such as feedthroughs, electrical cords, and magnets of the transfer arm should be detached. During the bakeout, the STM stage should be held up by the linear motion feedthrough attached at the bottom of the STM chamber to prevent the creep of the suspension springs of the vibration isolation system. A chromel-alumel thermocouple is attached to that linear motion feedthrough to monitor the temperature. During the bakeout, the temperature should be below 150 °C to prevent possible problems with the STM piezo tube scanner head. Another thermocouple should be attached on the transfer arm for the bakeout, and the temperature of the transfer arm should not exceed 100 °C since the transfer arm is susceptible to warping at higher temperatures. Also the transfer arm should be fixed to a vertical stand with a screw to prevent warping during the bakeout. After baking for about 24 hours, the pressure of the STM chamber stays around $2 \times 10^{-7}$ torr with the STM chamber still hot. Then the bakeout is turned off, and after about 12 hours the STM chamber cools down to room temperature with the final pressure of below $1 \times 10^{-10}$ torr.
2.2.2. Operation of STM

Since the invention of STM in 1981 [3], direct real space imaging of surface structures with atomic resolution has become possible and therefore STM has been employed in various fields of surface science. In operating STM, a sharp metal tip is approached to the surface under investigation within a couple of angstroms. When a small bias voltage (~ 1 V) is applied between the sample and the tip, a small finite current (~ 1 nA) flows due to the electron tunneling through the vacuum gap between the tip and the sample. This tunneling current changes exponentially as a function of vacuum gap distance, i.e. decreasing the vacuum gap distance by 0.1 nm will increase tunneling current an order of magnitude [4]. Therefore, as a metal tip attached to a piezo scanner scans over a surface area following surface morphology, the data of surface heights as a function of locations can be obtained. A lateral resolution of ~ 0.5 nm and vertical resolution better than 0.1 nm can be routinely obtained [4].

The STM used for this thesis experiments is a commercial Omicron UHV STM. The STM is manually placed on the sample by a wobble stick attached to the 8-inch flange. To do the STM, a sample holder is placed on the STM stage, then the STM is put on the sample holder, then the tip is approached to the sample using a telescope and the remote control of the STM control unit, and then the STM stage is lowered by retracting the linear motion feedthrough attached at the bottom of the STM chamber until the STM stage hangs freely. After all these procedures, one needs to check the resistance between the chamber ground and the $U_{\text{gap}}$ pin on one of the electrical feedthroughs; $U_{\text{gap}}$ pin is connected to one of the tripods of the STM to apply a bias voltage to the sample holder,
and this resistance should be infinite, otherwise the bias voltage will not be appropriately applied. This resistance becomes finite if the magnets and the copper blocks, attached to the suspension springs of the vibration isolation system, touch one another. If the resistance is infinite, the tip is autoapproached to the sample, and after some time the tunneling current will be seen on the oscilloscope connected to the STM control unit, and then one is ready to do the STM. As the tip scans over an area, the tunneling current is maintained at a constant value through a feedback circuit in the STM control unit and the heights of the surface area are recorded.

A Pt/Ir tip, manufactured by MAS (formerly, Materials Analytical Services), is mounted on the STM piezo scanner before the STM chamber bakeout. Using Pt/Ir tip has an advantage over commonly used tungsten tip in that Pt/Ir tip is relatively inert to oxidation and hence a rigorous tip cleaning process is not required such as ion sputtering of the tip in UHV. A tip zapper is connected to the $U_{\text{gap}}$ input of the STM controller to apply a voltage pulse, and by flipping the switch on the tip zapper, which triggers the STM tip to move suddenly backward, the tip can be cleaned. More details of the tip zapper are discussed in Ref. 5.

2.3. Transmission electron microscopy (TEM)

TEM has played an important role for decades in materials science and recently in the subnanometer scale microstructural analysis of thin film multilayers such as those found in integrated circuits [6]. TEM is analogous to optical microscopy in that high energy (typically, $>100$ keV) electrons are used instead of photons and electromagnetic
lenses instead of glass lenses. In TEM, however, the samples are thinned to a thickness of a few hundred nanometers typically by ion milling [6-7], and for this thesis experiments 5 keV Ar ions are used for the ion milling of Xe-implanted Ge. The thinned area of the sample is flooded with an electron beam of uniform intensity from an incoherent electron source of finite lateral width. The electron beam passes through the thinned area and a magnified image is formed using a set of electromagnetic lenses, and the image is projected onto a photographic plate or recorded by a video camera. While the use of visible light in optical microscopy limits the lateral resolution to a few hundred nanometers, much smaller wavelength of high energy electrons in TEM enables one to obtain a resolution of about 0.2 nm. Image contrast is obtained by the interaction of the high energy electron beam with the sample; a portion of the incident electrons will be diffracted, and using an aperture one or more diffracted beams can be selected for the formation of the image. The ion miller and TEM used for this thesis experiments are located at the Center for Microanalysis of Materials (CMM) at University of Illinois, and the TEM experiments in chapter 3 are performed by Dr. Young Kim, a member of the CMM staff.

2.4. Rutherford backscattering spectrometry (RBS)

During the past decades, RBS has evolved into one of the most frequently used techniques in thin film analysis [6-8]. When a monoenergetic light ions (in this thesis experiments, 2 MeV He ions) impinge onto a sample, a very small portion of the ions will undergo head-on collisions with the nuclei of the surface and bulk lattice atoms and be
backscattered; this Rutherford scattering process is understood in the context of a simple two-body collision. Since this scattering process is so rare, the attenuation of the ion beam intensity on its path into the target sample is relatively insignificant and is usually ignored. The backscattered ions will escape the sample and the energy of those ions can be analyzed. The energy distribution of the backscattered ions carries the information on mass and depth distribution of the target atoms, and hence by analyzing the RBS spectrum, the depth profile of the target sample is obtained. The RBS data can be fitted using a commercial software or analyzed using kinematic factors associated with the collision parameters. The RBS accelerator, HV Van de Graaff, used for these thesis experiments is located at the CMM at University of Illinois, and was operated by Brad Clymer and now by Mike Williams.

2.5. Experimental details

2.5.1. Ge sample preparation procedure

Ge(111) and Ge(001) wafers used for this thesis experiments are purchased from Eagle Picher. The samples are $1.5 \times 1.5 \text{ cm}^2$ pieces cut out of the Ge wafers. Ge oxide is water-soluble and the surface of a Ge sample changes to hydrophilic from hydrophobic after rinsing the Ge sample in running deionized (DI) water a few minutes. When the oxide is completely removed, a water wetting layer sticks to the sample surface for more than several seconds in the air. If the water wetting layer does not stay on the sample surface, the sample is probably contaminated and the sample should not be used for experiments. The Ge sample with the hydrophilic surface is subsequently put in a beaker
holding DI water, and the beaker is put in an ultrasonic cleaner for about 20 minutes to remove particles from the sample surface. The sample is then rinsed again in running DI water for a few minutes and dried using nitrogen gas. The sample is then put on a microscope slide and the microscope slide on a molybdenum sheet, and the sample is kept for about 30 minutes in a box equipped with an ultraviolet (UV) Hg lamp with the intensity of 25 mW/cm². The UV light generates ozone that reacts with the Ge sample to form about 1.8 nm thick homogeneous, nonpermeable amorphous GeO₂ layer [9].

The ozone-treated sample is then indium-bonded to the molybdenum sample stage, which is attached to the 3.5 inch molybdenum insert by 4 titanium screws, and this molybdenum insert is inserted into the molybdenum sample holder [10]. A schematic of the sample stage and insert is shown in Fig. 2.1. To enhance the sample heating efficiency, 20 mil-thick alumina tube spacers are inserted between the sample stage and the insert, and the reduced thermal conductivity allows one to heat the sample without heating the whole sample holder at the same temperature with the sample.

2.5.2. Experimental procedures

The Ge sample is heated by an electron beam hitting on the backside of the sample stage. A Williamson infrared optical pyrometer with the wavelength of 5 µm, temperature range of 100 °C - 550 °C, and precision of ± 5 °C is used to monitor the sample temperature during ion irradiation and sample annealing experiments. More details on the electron beam heating scheme are discussed in Ref. 10. Xe ions, produced
by the ion source, impinge onto the Ge sample surface making an angle of 50° from the surface normal with the ion flux detailed in section 2.1.2.

In the experiments on the bulk nanocavities in chapter 3 and the surface roughening of Ge during 5 keV Xe ion irradiation in chapter 5, the starting surfaces are prepared by desorbing the Ge oxide and annealing the sample at 620 °C for 90 minutes in an MBE chamber at the Epicenter; an STM image of the Ge(111) starting surface prepared in this manner is displayed in Fig. 2.2. After the annealing, the sample is in situ transferred to the STM chamber where the ion irradiation experiments are performed. In the study on the nanocavity formation, the Ge sample temperatures are 400 °C, 500 °C and 600 °C during 5 keV Xe ion irradiation; those temperatures are chosen, since below 400 °C and above 600 °C the nanocavity formation is deterred due to the unfavorable kinetics. In the study on the Ge surface roughening during 5 keV Xe ion etching, the sample temperatures are maintained at room temperature, 250 °C, 275 °C and 300 °C during the ion etching; those temperatures are chosen, since below 250 °C the Ge surface will be amorphized by ion irradiation, and at ≥ 300 °C the Ge surface appears flat in the length scale of 1 µm.

In the experiments on the annihilation of the bulk nanocavities on the Ge surfaces and individual 20 keV Xe ion impact on the Ge surfaces, both reported in chapter 4, the starting surfaces are prepared in the STM chamber by ion etching at 520 °C by 5 keV Xe ions with the ion fluence of $5.6 \times 10^{16}$ ions/cm²; STM images of the starting surfaces of Ge(111) and Ge(001) prepared in this manner are shown in Figs. 2.3(a) and 2.3(b), respectively. This high temperature ion etching of the Ge surfaces results in the starting
surfaces without any prominent surface defects other than steps. Right after the high temperature ion etching, the sample is cooled down to a lower temperature and ion-irradiated at that lower temperature, typically 275 °C or 305 °C. These temperatures are chosen since those are the temperatures low enough to observe large pits due to the annihilation of the nanocavities on the surface but high enough for the surfaces to remain crystalline; at 250 °C, Ge(111) surface is amorphized by the 5 keV Xe ion irradiation with the ion fluence of 5.6 x 10^{14} ions/cm^2. In annealing experiments in chapter 4, annealing begins right after the lower temperature ion irradiation is finished.

After ion irradiation or annealing, the sample is quenched to room temperature, transferred to the STM and imaged. All the STM images in this thesis are filled state images with the typical bias of ~ 2.0 V. Operation of the STM is described in section 2.2.2.

2.5.3. Calibration of STM

Whenever the STM piezo scanner is broken or replaced, it should be recalibrated. The easiest way to calibrate the piezo scanner is to use a sample with a well-known surface reconstruction and step height. In these thesis experiments, the lateral scan scale of the piezo scanner is calibrated using Ge(111) surface 2 × 8 reconstruction with unit cell size of 2.77 × 0.80 nm^2 [11-14], and vertical scale is calibrated using the bilayer step height of 0.326 nm for Ge(111). In the experiments on the annihilation of the nanocavities on the Ge surfaces in chapter 4, the lengths of the sides of the unit cell of the Ge(111) surface 2 × 8 reconstruction in the STM images were 15 % larger than known
values of 2.77 and 0.80 nm, and for the rest of the experiments, the lengths of the sides of
the unit cell of the Ge(111) surface $2 \times 8$ reconstruction in the STM images were 33 %
larger than known values. The conversion factors that should be used in converting the
height represented in bits in the STM images to real space height are shown in Table 2.1
and more details of the STM system calibration are discussed in Ref. 5.

Table 2.1. Conversion factors between the STM data and real space height.

<table>
<thead>
<tr>
<th>Setting</th>
<th>$R_1$</th>
<th>nm/bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>560 $\Omega$</td>
<td>0.0023</td>
</tr>
<tr>
<td>2</td>
<td>1.50 $k\Omega$</td>
<td>0.0053</td>
</tr>
<tr>
<td>3</td>
<td>4.99 $k\Omega$</td>
<td>0.012</td>
</tr>
<tr>
<td>4</td>
<td>10.08 $k\Omega$</td>
<td>0.015</td>
</tr>
<tr>
<td>5</td>
<td>O.C.</td>
<td>0.023</td>
</tr>
</tbody>
</table>

2.5.4. Calibration of pyrometer

One of the most important experimental parameters in these thesis experiments is
the sample temperature and thus the calibration of the optical pyrometer is crucial. Chey
compared the temperature readouts from a chromel-alumel thermocouple and from the
Williamson pyrometer for the calibration [10]. The results of his calibration are shown in
Table 2.2; all the temperatures are in degrees Celsius, $T_s$ is the sample temperature Chey
used for his experiments, $T_p$ is the corresponding Williamson pyrometer readout with the
emissivity $\varepsilon$. For example, when $\varepsilon$ is set at 0.21 and the pyrometer readout is 250 °C, the
sample temperature Chey reported is 270 °C. As the sample temperature increases, the
emissivity does not change between 165 °C and 245 °C, suddenly increases almost linearly between 245 °C and 325 °C, and then eventually drops, see Table 2.2.

Table 2.2. Chey’s pyrometer calibration results.

<table>
<thead>
<tr>
<th>T_s</th>
<th>165</th>
<th>190</th>
<th>220</th>
<th>245</th>
<th>270</th>
<th>295</th>
<th>325</th>
<th>430</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_p</td>
<td>150</td>
<td>175</td>
<td>200</td>
<td>225</td>
<td>250</td>
<td>275</td>
<td>300</td>
<td>450</td>
</tr>
<tr>
<td>ε</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.21</td>
<td>0.24</td>
<td>0.27</td>
<td>0.19</td>
</tr>
</tbody>
</table>

The emissivity of Ge as long as the samples are opaque due to free carrier absorption is

\[ \varepsilon_o = 1 - R = 1 - \frac{(n-1)^2}{(n+1)^2} = 0.64, \]  

(2-2)

where \( R \) is the reflectivity and \( n = 4 \) is the index of refraction of Ge. This emissivity is multiplied by the transmission coefficient of the sapphire view port at \( \lambda = 5 \) µm to give the emissivity number set on the pyrometer to measure sample temperatures. I measured the transmission coefficient of the sapphire view port equipped with the STM chamber using a steel tube in a furnace with the sapphire view port in front of the Williamson pyrometer, and the results are shown in Table 2.3. \( T \) is the temperature of the steel tube in degrees Celsius measured with a chromel-alumel thermocouple, \( TR \) is the transmission coefficient of the sapphire view port measured as the emissivity of the steel tube with the sapphire view port in front of it, and \( \varepsilon = \varepsilon_o \times TR \) is the estimated Ge emissivity with \( \varepsilon_o = 0.64. \)
Table 2.3. My Ge emissivity measurement results.

<table>
<thead>
<tr>
<th>T</th>
<th>200</th>
<th>225</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>550</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>0.69</td>
<td>0.69</td>
<td>0.72</td>
<td>0.72</td>
<td>0.73</td>
<td>0.75</td>
<td>0.77</td>
<td>0.80</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.44</td>
<td>0.44</td>
<td>0.46</td>
<td>0.46</td>
<td>0.47</td>
<td>0.48</td>
<td>0.49</td>
<td>0.51</td>
</tr>
</tbody>
</table>

These emissivity numbers agree well with the Ge emissivity numbers measured by Van Nostrand [5,15], which leads me to believe the results shown in Table 2.3 are more reliable than those shown in Table 2.2. The emissivity numbers in Table 2.3 were used during the experiments reported in chapters 3 and 5. For the experiments reported in chapter 4, the emissivity numbers in Table 2.2 were used during the experiments, and therefore the measured temperatures need to be corrected. During the transmission coefficient measurement experiments, I observed the change of 0.1 in the emissivity number set on the pyrometer gave about 10 °C difference in the pyrometer readout. Thus using this observation, I corrected the temperatures measured by using Chey’s calibration. Table 2.4 shows the corrected sample temperature $T$ in degrees Celsius from the temperature $T_s$ measured by using Chey’s calibration.

Table 2.4. Corrected temperature ($T$) used in chapter 4.

<table>
<thead>
<tr>
<th>T</th>
<th>245</th>
<th>275</th>
<th>305</th>
<th>520</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_s$</td>
<td>270</td>
<td>295</td>
<td>325</td>
<td>550</td>
</tr>
</tbody>
</table>
I once found the sapphire view port was partially coated with unknown material, though the temperatures of the experimental results reported in this thesis were not affected by that coating; a coated sapphire view port will be less transparent resulting in lower pyrometer readout. Therefore, one must check before each experiment if the sapphire view port is not coated with some other materials.
Fig. 2.1. Drawings of the molybdenum sample stage and molybdenum insert (from Ref. 10). (a) Plan view of the insert, (b) side view of the sample stage and insert, and (c) plan view of the sample stage. All units are in inches.
Fig. 2.2. STM image of the Ge(111) starting surface after annealing the sample at 620 °C for 90 min. The scan size is 600 × 600 nm².
Fig. 2.3. STM images of (a) Ge(111) and (b) Ge(001) surfaces etched by 5 keV Xe ions for 30 min. at 520 °C with the ion fluence of $5.6 \times 10^{16}$ ions/cm$^2$. The scan size is 600 × 600 nm$^2$.

2.6. References


