# Quantum Bridge Fabrication Using Photolithography

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## Abstract

The need for high-speed performance electronics in computers integrated circuits and sensors, require the fabrication of low energy consumption diodes. Nano fabrication methods require new techniques and equipment. We are currently developing a procedure to fabricate a diode based on quantum-effects. The device will act like a traditional diode, but the nanometer scale will allow it to reach high speeds without over heating. This new diode will be on a nano-bridge so it can be attenuated by an electromagnetic wave. The goal is to obtain similar current vs voltage response as in a silicon diode.

**Research Category (Please Circle)**

ERULF: Physics Chemistry Biology Engineering Computer Science Other________
CCI: Biotechnology Environmental Science Computing

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**Introduction**

The few decades following the introduction of the transistor in the late 1940's have seen a very dramatic change in the electronics industry. The miniaturization that has resulted leaves scientists to wonder about its limits. Complete systems now appear on a wafer thousands of times smaller than the single element of earlier networks. The miniaturization of recent years has resulted in systems so small that the primary purpose of the packaging is simply to provide some means of handling the device and ensuring that the leads remain properly fixed to the semi-conductor wafer. The limits of miniaturization appear to be governed by three factors: the quality of the semiconductor material, the design technique, and the limits of manufacturing and processing equipment (Boylestad, 1996).

The first semiconductor device to be introduced was the diode. It is the simplest device, but play a vital role in electronic systems. Basically, a diode functions like a switch. Silicon diodes are the most common type of diode, but they cannot be used for high frequency applications. For high frequency applications small devices need to be fabricated. When building a small device, quantum effects must be considered. The difference between quantum electronic devices and other devices is the discrete quantity of electrons that pass through the device during operation. This equation is used to determine the quantum threshold:

$$R = \rho * \frac{l}{A} \quad \Rightarrow \quad A = \rho * \frac{l}{R} \tag{1}$$

Where: R = resistance

l = length

A = area

ρ = Resistivity constant for each material

By knowing the area (A) after calculations, the height and width can be calculated using this equation:

$$H = \frac{A}{W} \qquad (2)$$

Where: A = area

H = height

W = width

When we consider small devices in nano-scale, there are some physical effects that differ from the macroscopic scale counterparts. Developments in the micro engineering have created a new interest in some effects that occurs at the nano-scale (10^-9 meter). Micro engineering is the technology that studies and fabricates three-dimensional structures and devices on the micro scale (10^-6) (Sandoval, 2000). This includes areas like micro mechanics and microelectronics. Micro mechanics analyze moving parts of microchips and microelectronics produce electronics circuits in Silicon chips. Micro machining is the name of the technique used to produce micro constructed devices. The combination of electronics and mechanics in one microstructure is called Micro-Electromechanical Systems (MEMS).

Photolithography is a basic technique most often used in the fabrication of MEMS structures. Photolithography is a process by which the pattern of an integrated circuit is imprinted on a silicon wafer coated with a photoresist mask containing the pattern on it and spinning ultraviolet light through it (Morris, 1992). This process is also used in the design of Nano-Electromechanical Systems (NEMS). In the photolithography process, an ultraviolet (UV) source is used to expose photo resist polymers. The resulting patterns are used for subsequent micro machining processes.

Before photolithography a mask is produced. The mask is typically made in Chromium coated on a glass sheet. There are two different types of masks and two different types of photo resist materials: positive and negative. For a positive mask, excess material is removed from around the pattern. A negative mask produces the opposite effect. The UV light passes through the mask and hit the photoresist material, which may become stronger or weaker, depending of the type.

Two common types of photo-resist are: polymethyl methacrylate (PMMA) photo-resist and Epoxy (SU-8) photoresist. PMMA is a positive photoresist and it weakens in UV light exposure. SU-8 is a negative photoresist and it gets strengthens in the presence of UV light. After photolithography, both resists are developed in their respective developers. The photo resist used in this project was PMMA. The main reason being that PMMA is easier to be removed for the final lift-off process.

There are ways to do metal deposition. One of them uses an ion source to sputter materials on the target- Broad Bean Ion Mill. In this machine, Argon ions are accelerated at a piece of metal, removing trace amounts that deposit on the. This process requires high-vacuum and high temperatures. The thickness of the metal that is deposited is determined by the time of process and the current supplied to the ion gun, as well as the flow of Argon.

**Methods and Materials**

We used 10mm by 10mm by 0.06mm thick glass samples. Because cleanness is very important, samples are made in the clean room at room temperature. Every glass sample was cleaned with high quality acetone in an ultrasonic cleaning machine and rinsed with 99% pure ethyl Alcohol. Rinsing and drying process are done on the photoresist spinner machine. The speed is set to 3000rpm for 60 seconds during the initial cleaning process. During the PMMA coating process, the speed is varied between 2000rpm to 4000rpm. This part of the process must be done in the dark or at the lowest light level possible because PMMA reacts in the presence of light. One hundred micro liters is deposited on every sample. Every sample was spun coated and dried for 60 seconds. The next step was to bake the sample for 3 to 5 minutes at 100 °C, on a hot plate. All samples are made before going to the next process.

The following defines is the photolithography process. We used a negative mask. A 45mw UV exposed the samples for 30 seconds to 3 minutes. UV beam is aligned on the pattern from the mask. After all the samples were exposed to UV, the samples were developed using a developer. The developer removes all the PMMA that was exposed to UV light. The development time was 20 seconds. Following the development process, the samples were rinsed with DI water (de-ionized water). Baking the samples for another 3 to 5 minutes in a hot plate sets the polymer.

The next stage was Titanium (Ti) deposition on the samples. For this, the broad beam ion mill machine was used. The time of deposition was approximately 15min at 10 mA (mili Amps) on the cathode. The desired layer thickness for the samples was 10 nanometers. After deposition, the thickness of Ti in the samples is measured with the profilometer.

The following defines the lift-off process. In this process every sample are dipped in acetone to eliminate PMMA not patterned on the samples. This will leave the patterns in Ti only, on the glass samples. Every sample was investigated on the microscope and afterward determine whether they are worth to keeping.

The next step consists of oxidation the Ti using the Atomic Force Microscope (AFM). In this step, each sample is inserted on the AFM in a humidity control chamber. The humidity control chamber will maintain constant the humidity level, so that the AFM tip can stay more stable. In addition, the relative amount of humidity will control the thickness of oxidize lines. The higher is the humidity equals thicker lines of oxidation as shown in Figure 1. In the oxidation process, the water on top of the sample will form $OH^-$ ions, which oxidize Ti. The voltage applied to the sample was between 6 to 12 volts, with the AFM tip being ground. The pattern used for oxidation was triangular shaped as shown in Figure 2. We oxidize two opposing triangular shapes for each nano wire, so that a small gap of a few nanometers is left on the non-oxidize material. The Figure 3 presents the small gap of few nanometers. After the oxidation, measurements of the total resistance for the device approach the Mega ohms, the desired result resistance. Resistance was measured using a Micro-Probe station. The equipment used to measure the resistance is a Keithley 236 Source Measure Unit, which can measure current on Pico amps (pA) scale.

The final stage of the process will be to etch under the nano-wire, using HF (hydrofluoric acid). This will give a bridge like structure. Acoustical actuation of the nano-wire bridge will change the physical properties of the material and at the same time if a current is applied, the flow of electrons will be changed. This will give a similar response of a Silicon diode.

Modifications to the above have occurred often. The last review on the process was made on November 27, 2000.

## Results

Currently a Ti pattern has been obtained. The picture is shown on Figure 4. The resistance across the wires was on order of kilo ohms. A resistance measurement was taken and is shown on Figure 5. This figure illustrate a Voltage vs Current graph and indicates that the current increase linearly with increasing voltage across the wires. The expected resistance for the device has not been reached yet. The graph expected is similar to a diode response as shown in Figure 6 and is non-linear.

## Discussions and Conclusions

As seen in Figure 7 titanium wires are not completely smooth and there are some residues of titanium left on the substrate. This is from overexposing the samples to UV light or the underdevelopment of the samples. Malfunctioning of the clean room facilities for two weeks during the period of research introduces impurities such as dust, which also had undesirable effects.

A need of a more uniform UV source is required on the process of photolithography. Exposure of photo resist needs a uniform UV light to create more efficient patterns on the samples.

Additionally, the humidity control chamber has not yet been made. The humidity in the room changes, thereby affect the AFM readings. In the process of oxidation the humidity should be held. Keeping the humidity at one level will make more accurate oxidation patterns.

As shown previously in the results, this experiment is on early stage. More research must be done to ensure quickness and low cost in the fabrication process. The reason that the last stage is not done yet is because of the need for better nanofabrication equipment. Further fabrication processes are on going at Cornell Nanofabrication Facilities, University of Cornell.

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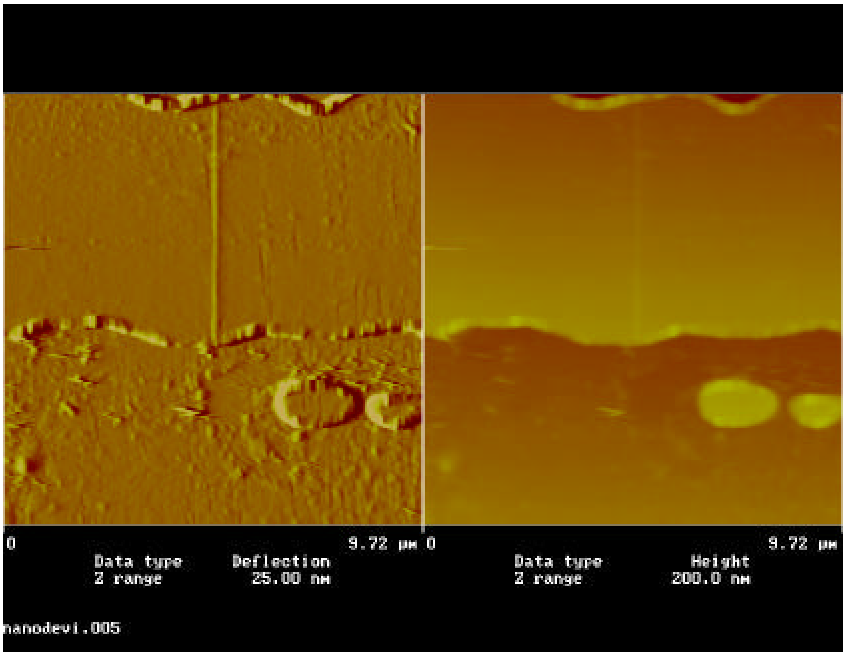


Figure 1: Oxidation line on Ti

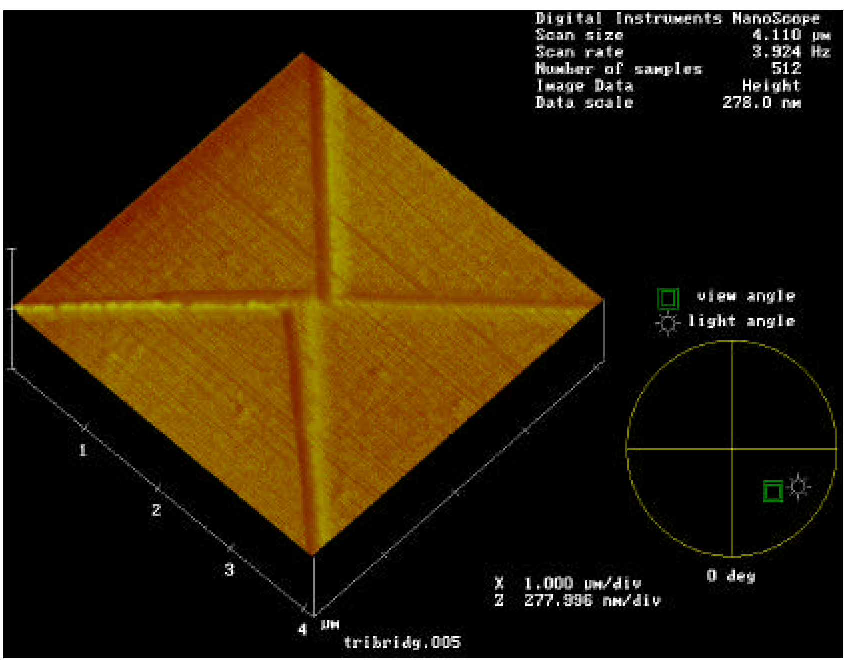


Figure 2: Triangular Oxidation Shape

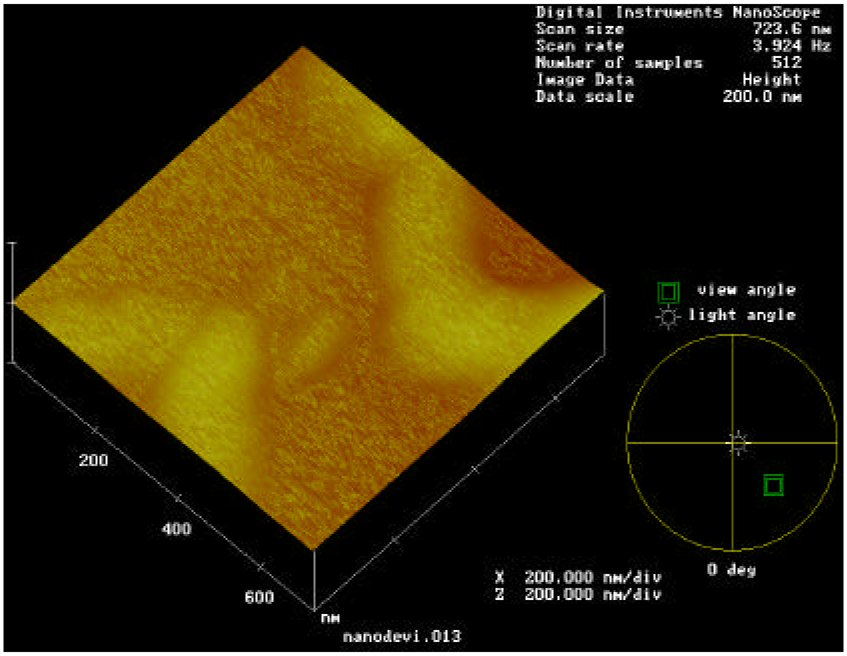


Figure 3: Few nanometers gap on Ti wire

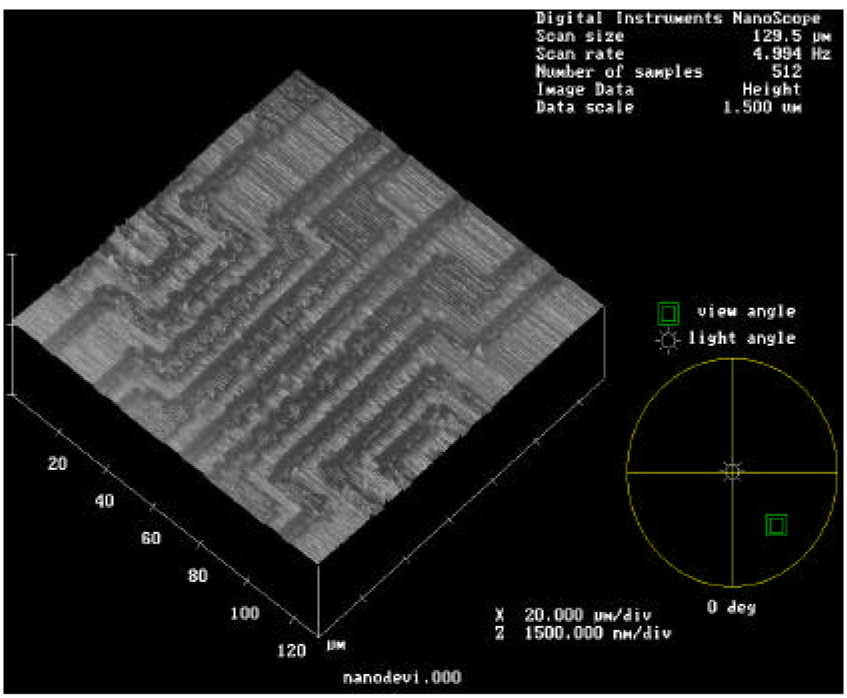


Figure 4: Ti wires Pattern

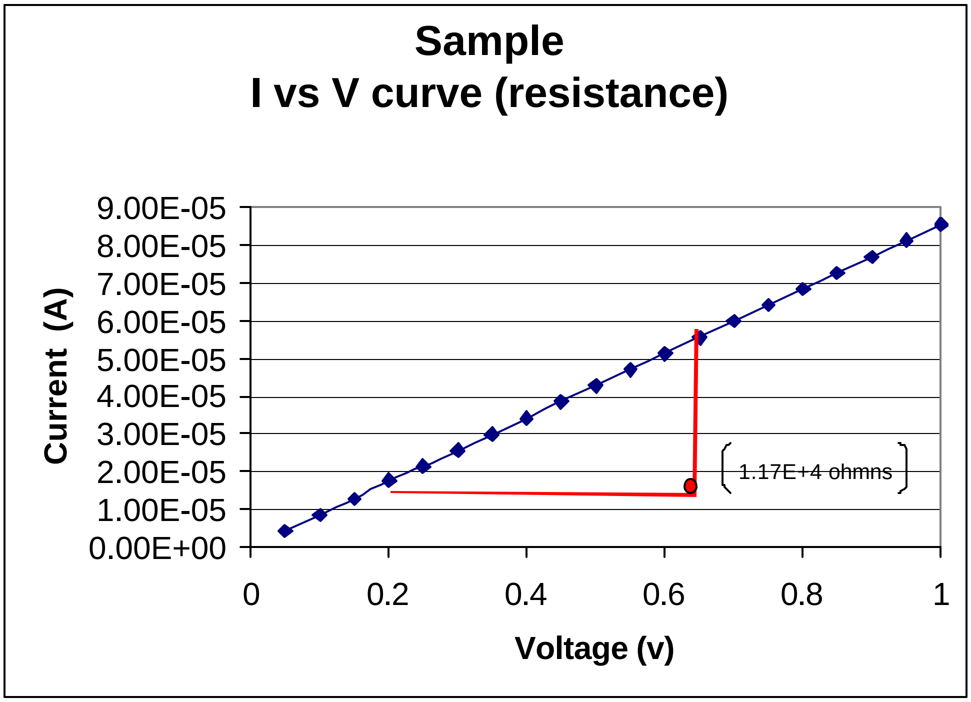


Figure 5: Current Response

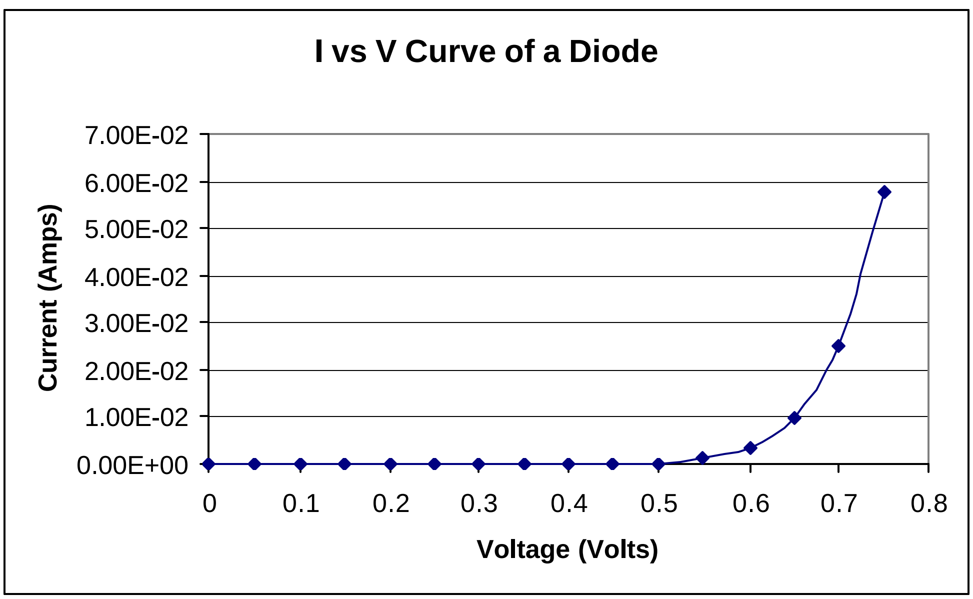


Figure 6: Expected response

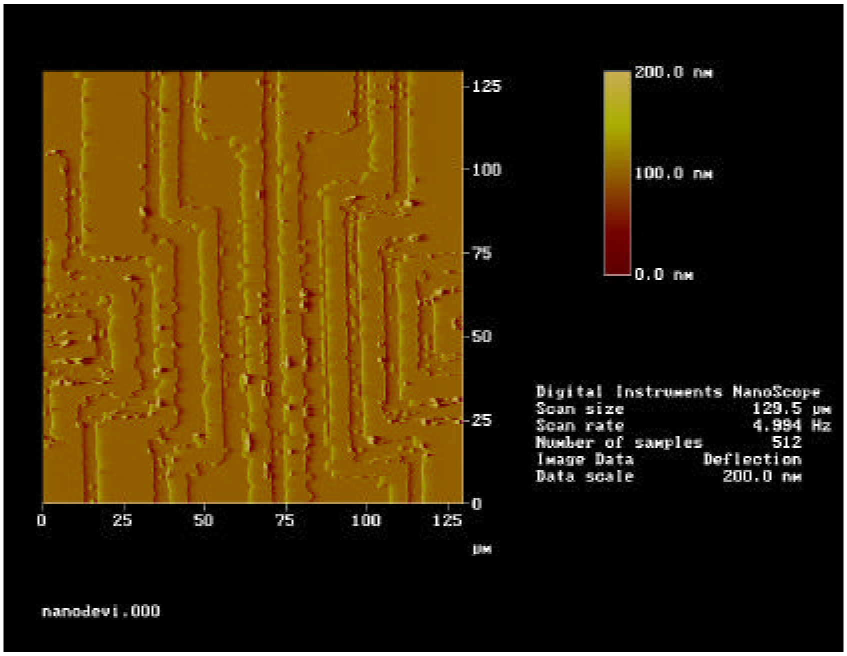


Figure 7: This picture shows the residues of Ti close to the wires