

Simple device to study tunnelling of electrons through nano junction using tungsten wire

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Abstract

In present work, the tunnelling junction was fabricated using an electrochemical etching method. The I-V characteristics were recorded before and after the tunnelling junction between tungsten tips was formed. We have observed that before etching current-voltage followed Ohm's law shows linear relation between them. After nano junction was formed non-linear relation between current and voltage was observed. Estimated values of resistance from the I-V curve were found to be increases for tunnelling junctions indicating flow of the current in the circuit is due to tunnelling effect. Linear fitting of the F-N plot shows the current was due to field emission of electrons.

Keywords: - Tunnelling junction, Electrochemical etching, Field emission, F-N plot

1. Introduction

The particle passes through a potential barrier if the energy of the particle is less than height of the potential barrier, this phenomenon is called quantum mechanical tunnelling [1]. In Quantum mechanics, tunnelling is possible because of the wave-like nature of the particle. Tunnelling is a purely quantum mechanical effect arising from wave-particle duality and Uncertainty principle [2]. This effect is important in many applications in technology like semiconductor devices, nuclear fusion, scanning tunnelling microscopy (STM) [3,4,5].

Tunnelling junction is generally an electronic junction which is a few nanometres thick where electrons can tunnel through a thin insulating barrier (quantum junction) between two conductive materials [6]. There are different types of tunnelling junctions – Metal Insulator metal junction which is used in STM. Superconductor Insulator Superconductor – This junction used in superconducting quantum circuits and quantum computing.

Ferromagnetic Insulator Ferromagnetic (Magnetic tunnelling junctions) – used in MRAM, Magnetic sensors, Spintronics [7,8,9,10].

Field emission is nothing but the emission of electrons from the surface of a material (metal) by applying a strong electric field (10^7 V/m). For thermionic emission heating of the filament is required but field emission doesn't need heating hence this is also called cold emission. Field emission is a purely quantum mechanical process and is governed by quantum tunnelling [11]. This phenomenon is useful in many applications in technology like Scanning tunnelling microscopy (STM), Field emission display (FED's), Vacuum microelectronics [12,13,14].

In present work a simple device to study lateral tunnelling phenomenon was constructed using tungsten wire. The electrolysis etching process was used to make a tunnelling junction between two tungsten tips. I-V characteristics were studied before formation of junction (ohmic contact) and after tunnelling junction was formed. **Fowler-Nordheim (F-N)** was used to study Field emission of electrons from tungsten tip.

2. Experimental setup

The simple device used to study lateral tunnelling phenomenon is shown in Figure 1.

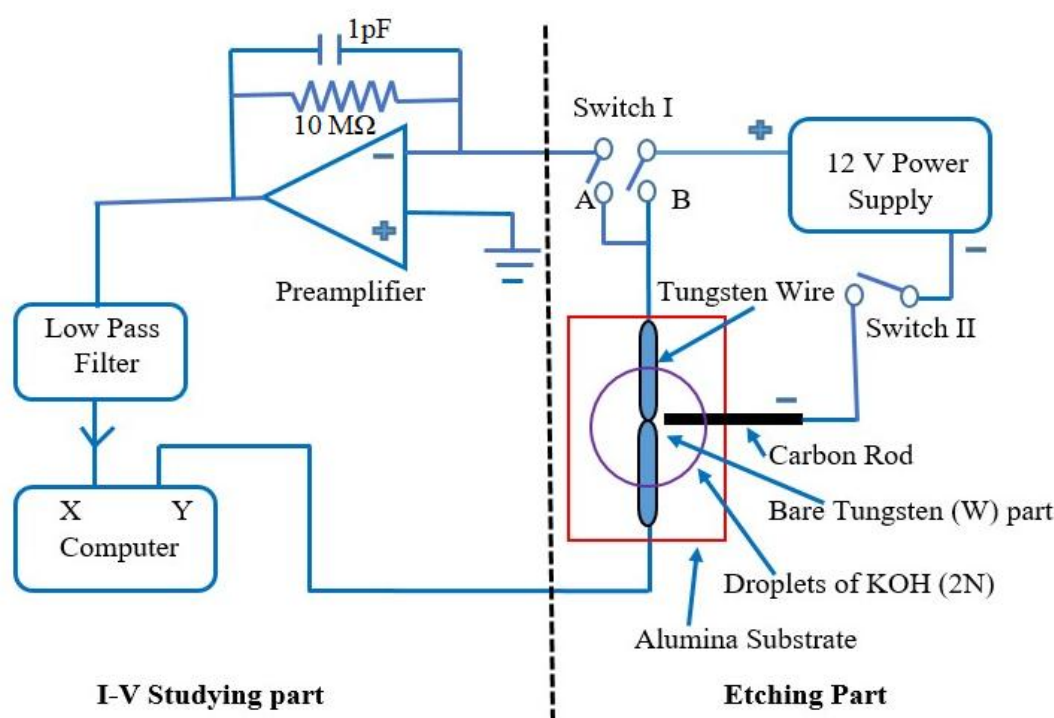


Figure 1. Construction of simple device to study lateral tunnelling phenomenon

This device consists of two parts.

- 1) Making tunnelling junction using electrochemical etching method [15]
- 2) To record I-V characteristics before and after tunnelling junction was formed [16]

Following components are used to construct this device – tungsten wire (0.2 mm), preamplifier, power supply (± 12), carbon rod (0.5 mm), Teflon tape to cover tungsten wire, low pass filter, and computer interfacing. We have insulated tungsten (W) wire by using Teflon tape and fixed it on the alumina substrate. Teflon insulation stops the flow of leakage current. Current-Voltage (I-V) data recorded before the junction was formed.

Step 1: Electrochemical etching of the tungsten wire –

Firstly, Teflon coating was removed from the central part of the tungsten wire as shown in figure 2(a). 2N normal solution of KOH was used as etchant. Positive and negative of the power supply connected to tungsten wire and carbon rod respectively as shown in figure 1. Carbon rod was adjusted near the central region of the tungsten wire. Close switch (I-B) and switch (II) and open switch (I-A) during the etching process. The electrochemical etching started when dropwise etchant (KOH solution) was put on the central bare tungsten part. Only the bare part of the wire was etched as the rest part is protected from etching by Teflon cover. The progress of the etching process is shown in Figure 2 (b-d).

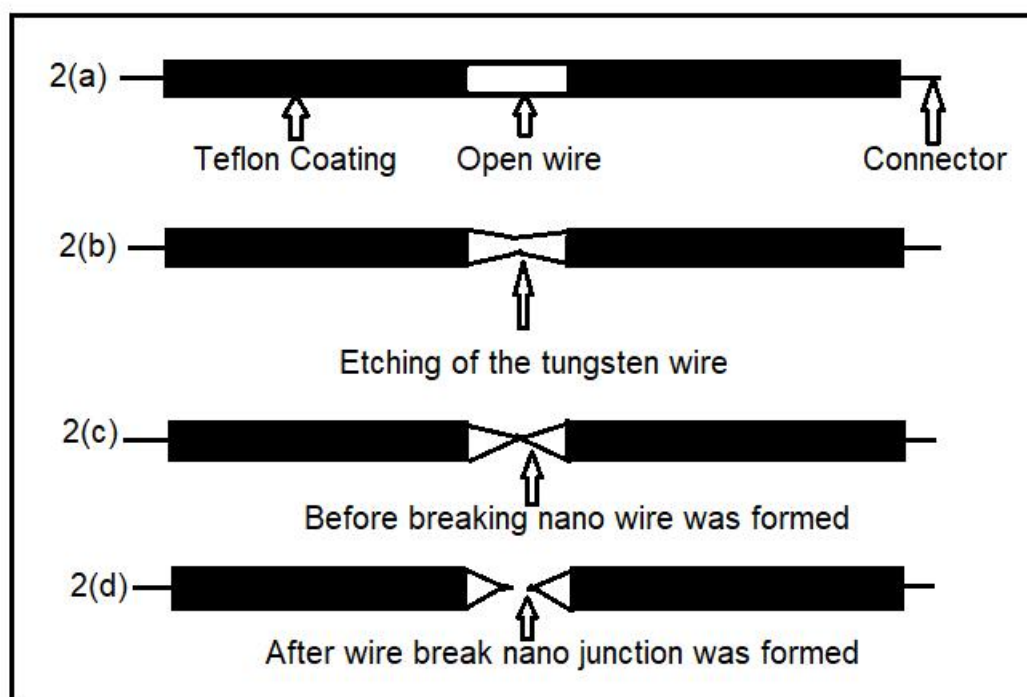


Figure 2 (a-d). Steps during etching of tungsten wire.

The etching of the tungsten tip was constantly monitored under high resolution optical microscopy (X40). When a sharp break nano junction was formed then switched off the power supply to avoid possibility of further etching. The remaining etchant (KOH) was removed by rising formed nano junction using distilled water and cotton carefully.

Step 2: To study I-V characteristics –

To study I-V characteristics after the tunnelling junction formed, current was grabbed by applying bias voltage across the break junction and current-voltage data was recorded by using the computer interface.

3. Result and discussion

In present work we have recorded values of current for applied biasing voltage from -0.4 to 0.4 Volt before etching started using a computer interface. Figure 3 shows I-V characteristics before the junction was formed.

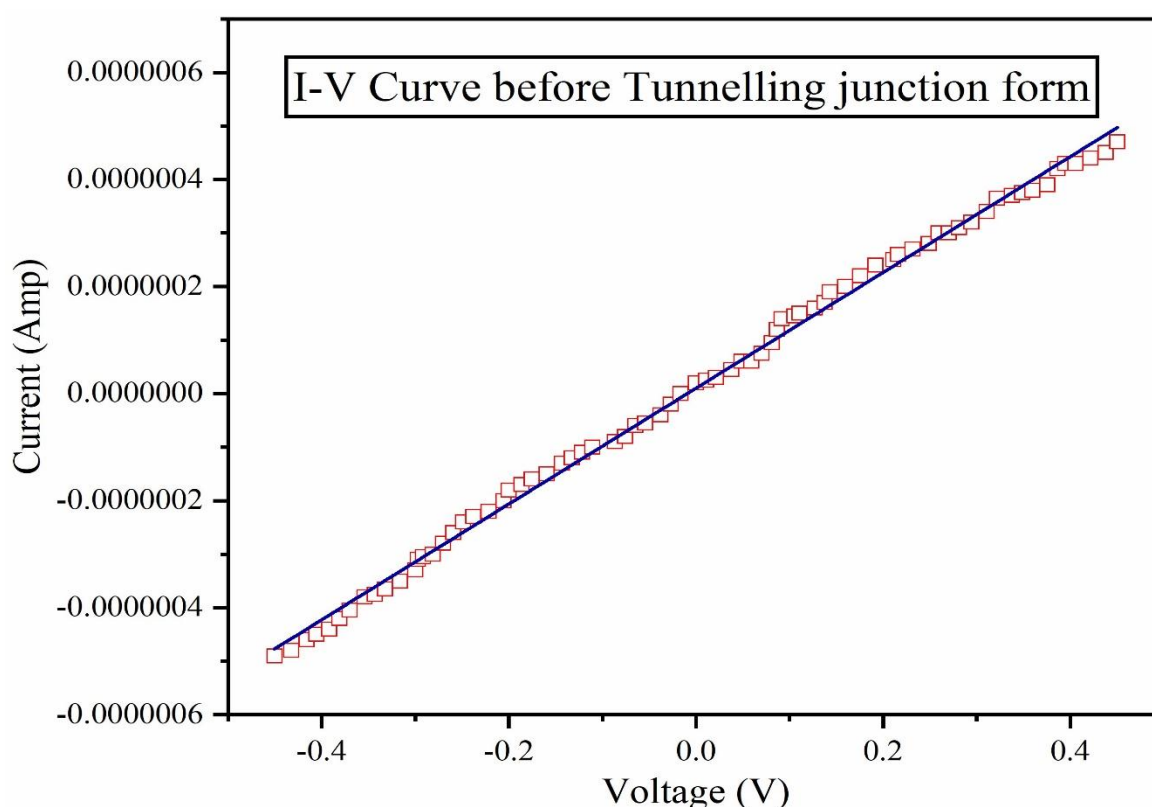


Figure 3. I-V characteristics before junction was formed

The current-voltage relation follows Ohms law at low bias voltage. From the graph the calculated value of slope is 1.098×10^{-6} . Therefore, from slope resistance of the wire calculated as

$$Resistance = \frac{1}{slope} \quad (1)$$

Resistance was found to be 0.920 MΩ. The high value of resistance was due to contact resistance in the circuit.

The value of current is recorded by varying applied bias voltage -1.5 to 1.0 Volt across the break nano junction by using the computer interface. The values of current-voltage noted in table 1. After the tunnelling junction was formed the current-voltage (I-V) characteristics changed from straight line (figure 3) to non-linear curve as shown in Figure 4.

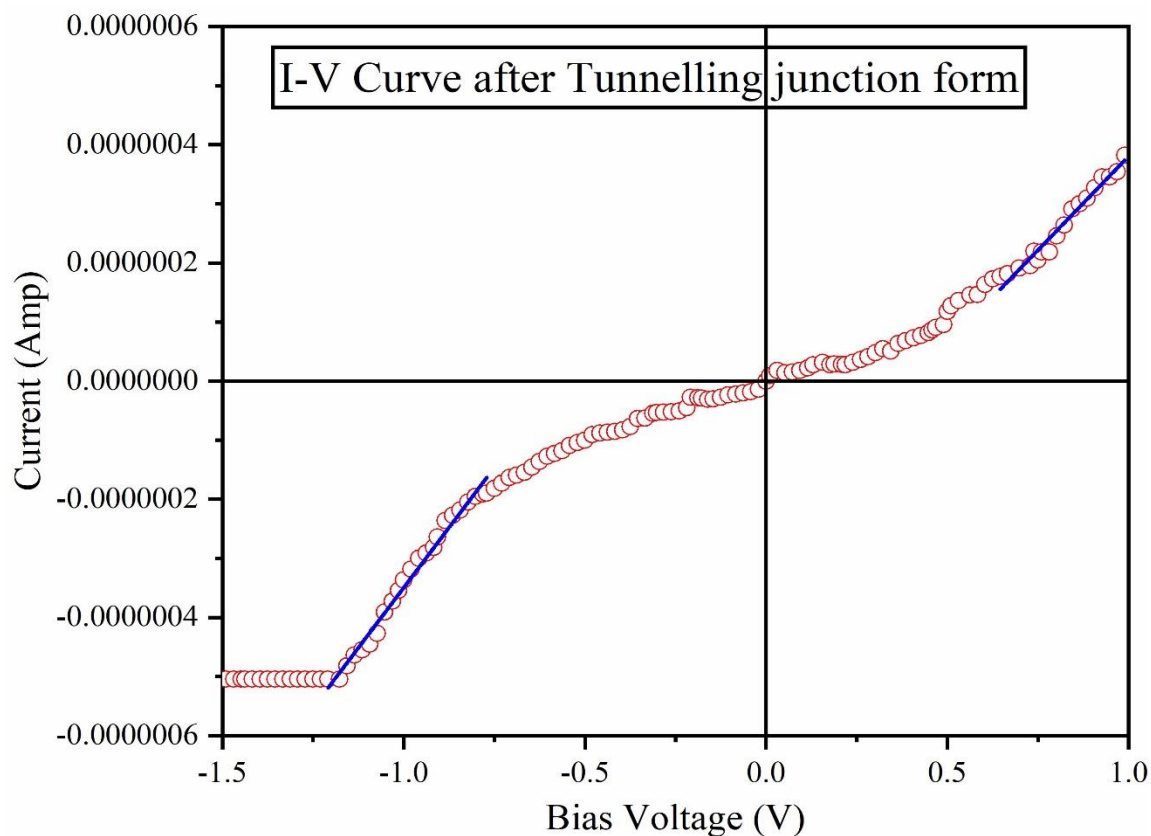


Figure 4. I-V characteristics before junction was formed

To understand the nature of transfer of electrons in the tunnelling junction. The straight line in the positive and negative region fitted separately and resistance was calculated. The estimated values of resistance in the positive and negative region were 1.2 MΩ and 1.59

MΩ respectively. The obtained high values of resistance indicate the current is due to tunnelling of electrons called as tunnelling current [17].

By using Fowler-Nordheim (F-N) theory field emission of electrons was studied. F-N equation can be stated as [18]

$$\frac{J}{E^2} = A \exp\left[\frac{-B}{E}\right] \quad (\text{A/cm}^2) \quad (2)$$

$$\text{Where, } A = \frac{e^3 m}{16\pi^2 \hbar m_{ox} \phi_0} = 1.54 \times 10^{-6} \frac{m}{m_{ox} \phi_0} \quad (\text{A/V}^2) \quad (3)$$

$$B = \frac{4}{3} \frac{(2m_{ox})^{1/2}}{e\hbar} \phi_0^{3/2} = 6.83 \times 10^7 \left(\frac{m}{m_{ox}}\right)^{1/2} \phi_0^{3/2} \quad (4)$$

Where, e = charge on the electron, m = mass of the free electron, m_{ox} = mass of the electron in the oxide, $2\pi\hbar$ = Planck's constant, and ϕ_0 = barrier height expressed in electron volts (eV). J = Current density (A/cm²)

E = Applied field strength (V/cm)

The plot of $\ln(I/V^2)$ Vs $1/V$ gives straight line known F-N plot. Where I is the tunnelling current recorded for different applied bias voltage (V).

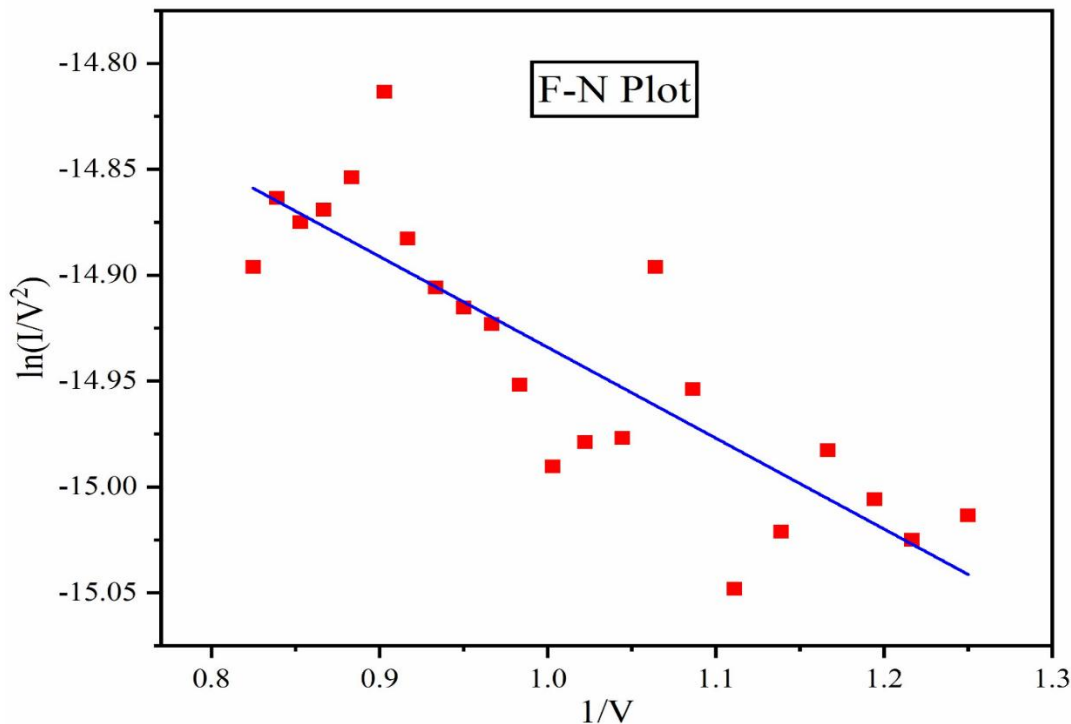


Figure 5. F-N Plot

In present study we have plotted a graph of $\log(I/V^2)$ Vs $1/V$ as shown in figure 5. This graph is linearly fitted; hence the F-N equation was satisfied. The F-N plot shows that the current was due to field emission of electrons from the tungsten tip in presence of strong electric field.

Conclusion

Tunnelling junction was fabricated using an electrochemical etching method. The I-V characteristics were studied before and after the tunnelling junction between tungsten tips was formed. I-V characteristics show expected linear relation between current and applied voltage satisfied Ohm's law before junction was formed. Non-linear relation between current and voltage was observed after nano junction was formed between tungsten tips. It is observed that estimated values of resistance from I-V curve in positive and negative regions were increased for tunnelling junctions, indicating flow of the current in the circuit is due to tunnelling effect. F-N plot shows that current was due to field emission of electrons.

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