Portable Nano Scanning Technology (PNST)

Aarush Tulsyan[1], Anish Bhat[1], Rohan Shankar[1]

[1]Westwood High School

Abstract

The advancement of atomic-level science typically requires costly laboratory equipment, limiting research to well-funded institutions. My project addresses this issue with a portable, low-cost scanning microscope, allowing smaller research teams to conduct atomic-level investigations without usual financial and setup constraints. The core innovation is a vertical lever system enabling precise 6-nanometer adjustments in the z-direction, crucial for positioning the tungsten tip to record tunneling currents effectively. Using an amplifier and Fourier transformation, my portable STM (PNST) interprets these currents to create detailed maps of sample surfaces. Trials have shown promising results, producing accurate images of atomic structures on metallic surfaces, revealing individual atoms and their local arrangements. This affordable, compact microscope is particularly valuable in educational settings, overcoming traditional STM limitations like size, installation complexity, and cost. My design facilitates advanced materials science research in educational institutions, enabling the study of new materials and alloys at unprecedented detail.

Field of the Invention

The present invention relates to the field of atomic microscopy.

Background of the Invention and Prior Art

Currently, the Scanning Tunneling Microscope (STM) is an industry/lab only equipment which is meant for conducting research amongst researchers or amongst industry applications for testing and designing. On the other hand, several STMs have been created at home as DIY projects for hobbies.

My

goal was to create a microscope that is cheap by adapting various features from these DIY microscopes, but adapting them towards a commercial use by adding various market oriented features designed for everyday customers like a small size and adding wall charging capabilities. This allows customers to use technology similar to the STM without having industry level knowledge.

Brief Description of the Invention

The Portable Nano Scanning Technology (PNST) works by scanning the current at an atomic scale using a tip and then constructing a topographic map based on the amount of current perceived, which is inversely related to the distance between the tip and the metallic surface. The fundamental concept of physics employed in the PNST is quantum tunneling, the property of electrons to pass through minuscule distances between metallic surfaces in the form of current. A conductive tip, often made of tungsten, provides a high resolution for scanning the surface. The piezoelectric scanner precisely moves the tip in x, y, and z-axes with atomic accuracy using the piezoelectric effect, which occurs when materials expand or contract under the influence of an electric field. Current amplifier amplifies a minuscule tunneling current passing from the sample to the tip. The feedback loop adjusts the tip's height to maintain a constant tunneling current enabling the mapping of the surface's topography by using the relative potential difference to create a topographic map of the surface.

Detailed Description of the Invention

The Portable Nano Scanning Technology (PNST) (depicted in fixtures [1-]) works by scanning the current at each individual atom using a tip and then making a topographical map based on the amount of current perceived (since more current is a result of a smaller distance between the tip and atom). This is all possible thanks to the phenomenon of quantum tunneling which allows electrons in the form of current to travel between 2 extremely small spaces. To achieve this phenomenon however leaves us with 3 main problems: Traveling extremely small distances (~1nm resolution), completely isolating the perceived current to prevent inaccurate readings and amplifying the current (which is around 10 nA) to a readable level.

This is all possible by combining 7 different parts:

A. **The tip holder**

The tip holder [figure 2] is a clamp based system which is meant to hold the tip [201] in place. The entire frame [208] of the tip holder is made up of non conductive material like ceramic. If needed, the material for the frame could be any form of non conductive vacuum compatible material like acrylic or various ceramics. Inside the frame is a circular disc [203] through which the tip [201] goes through. The disc is put in place to keep the environment around the tip [201] a closed system and avoid minimal contact with the environment. Immediately passing through the disk [203] is a screw [207] which clamps down on the tip [201] once screwed in. At the end of the screw is an insulating cap [209] to avoid any form of conductive contact with the tip [201]. The screw [207] pushes the tip [201] against the absorption plate [206], a piece of conductive metal to absorb the current from the tip [201]. Right above the absorption plate [206] sits a metal cylinder [205] to which the absorption plate [206] is soldered to create a strong connection. This metal cylinder [205] will serve as our gateway to transmit the current out of the tip [201] and into the piezo holder from where it will be moved to the circuit for processing. Surrounding the metal cylinder [205] is a screw frame [204] which is coated with an insulation material [210]. On the other end of the screw [207] is a weight[202] to adjust the center of mass.

Notes

I. The tip holder was created in such a way that it could be easily removed from the piezo holder. This was done since the tip holder is a part which is meant to be accessible to the user without him having to disconnect more of the PNST. This was done by making the top a metal in the form of a screw [204] which has an equivalent bearing in the piezoholder. The metal cylinder [205] allows for direct connectivity into a similar conductive material that lets the current be absorbed. This allows the user to simply unscrew the tip holder when he needs to interact with it (for eg. changing tips) and then screw it back in.

II. The metal cylinder [205] should be coated with a conductive but highly unreactive metal (inert metals like platinum/gold/silver work well) to avoid oxidation when removed, as to not interfere with the conductivity. If the user wants to take it out for a long term, a cap can be placed to avoid oxidation.

III. The production process for the tip is separate from the tip holder to reduce extra costs. The tip is created by twisting the ends of a 22 gauge Tungsten wire in opposite directions until the center becomes thin to cut using a knife. Due to the high density and high tensile strength properties of Tungsten, the tip is very sharp, often below a thickness of 20 nm. This process is known as Torsion Effect.

Manufacturing process

The manufacturing process would involve preparing several different components and then putting them together.

I. First the ceramic frame along with the disc [208,203] would need to be machined. This could be done simply using a mill. A threaded hole is also milled into side for future steps.
II. Next, the metal screw [204] on the top can be produced using a simple threading machine.
III. The metal cylinder and absorption plate [205,206] can also be simply cut either together or separately using various metal machining tools.
IV. The plating on the metal cylinder [205] can be done with any inert metals like silver via electroplating/painting.
V. The insulation material is also applied on the interior of the metal screw frame [210,204].
VI. A simple screw along with a printed cap can be used for [207,209].
VII. The combination of [205,206] is then glued into [204,210,208,203] together.
VIII. The threaded hole is then used to fit the screw.

IX. Finally a weight is glued at [202] to ensure a proper center of mass.

B. The Piezo head

The piezo head [figure 3] is a system whose main purpose is to move the tip very small distances (atomic lengths) to make a scan of the surface. The controlling element of the piezo head is the piezo amplifier [301]. It is made up of brass and ceramic piezo. The ceramic is divided into 4 quarters [301 a,b,c,d]. As seen in [figure 4], by applying currents in the directions we want (-X,-Y), we force the piezo material [301] to expand in those directions according to the piezoelectric effect. On the other hand, by applying a negative current, we force the piezo material [301] to contract and pull the piezo [301] back in those directions (+X,+Y). As a result, the piezo [301] ends up pivoting in the direction of (-X,-Y). Since the expansions and contractions are very small (a few nm), we end up moving the distance of an atom. Furthermore to move in the (Z-axis), current could be simply applied in all quadrants [301 a,b,c,d] to cause the piezo [301] to expand and push the tip down or alternatively remove current from all quadrants [301 a,b,c,d] and contract it to push it up. Connected to the piezo amplifier [301], we have a ceramic frame [302]. This ceramic frame [302] is fitted with a threaded bearing [304] inside it to house the tip holder. Towards the top of the ceramic frame [302] is another metal cylinder that connects to the metal cylinder of the tip holder to absorb current. The current is then taken out using a wire which is fitted into the socket hole [305].

Manufacturing process

I. The piezo amplifier [301] is taken and cut into 4 different quadrants [301 a,b,c,d] with wires soldered to each quadrant.
II. The metallic cylinder [303] is cut from a conductive metal (preferably also plated with the same material as that of the tip holder) and a small hole [305] is milled from the side.
III. Then in the ceramic frame [302], which is milled in the center and in a small hole [305] towards the top, the metal cylinder [303] is glued such that the 2 holes overlap [305].
IV. A wire is connected to the socket and a threaded bearing [304] is fitted into the frame [302].

C. The motorized frame

***** For [502],[503],[504],[505], there is a hole and their components ([502] - piezo, [503-505] - screw) associated with them. The context should make it obvious what the token refers to.

The motorized frame [figure 5] is a framework meant to not only act as the body to the PNST, but also help move the tip. This is important since piezoelectrics alone can't move large distances (for a low price). Instead we use a leadscrew styled mechanism that helps it move down. In the design, we have the top metallic frame [501] which consists of 4 holes [502,503,504,505]. The biggest hole [502] is just a slight bit smaller than the piezo amplifier [502] so that it can simply sit on the frame [501]. 1 mm behind the center of the piezo are 2 holes [503,504] equidistant from the center. In each of the 2 holes [503,504] are the screws [503,504] and their respective bearing [506,508]. Then some distance from the center is the third screw [505] which is meant to hold the third screw [505] and bearing [507]. Since the top mechanical frame [501] is not fixed, it will move down if the bearings [506-508] move down, which they will as the screws [503-505] rotate. Additionally we have elastic pullers [509.510] on the sides (in the form of rubber band or spring to pull down the frame [501]. The two hindscrews [503,504] are fitted on threaded gears [514,515] which are linked to another driver gear [513] that is connected to a stepper motor [516]. On the other hand, the forescrew [505] is connected to a simple thread - motor adapter [518] and then connected to the motor [517] to make it move. The main reason for using such a setup is to allow it to achieve really precise movement (in the order of nm). When the forescrew [505] goes down, the hindscrews [503.504] act as a pivot, resulting in angular motion. Since the piezo amplifier [502] is only a part of the way there, it will move a much smaller distance. Paired with the small step of the stepper motor [517], the small pitch of the screw [505] and this reduction factor, moving the forescrew [505] lets you precisely adjust the piezo amplifier enough on the Z-axis so that it can reach the atoms. Below the piezo amplifier [502] is a conductive plate [511] used for holding the sample. It is separated from the remaining part of the bottom metal frame [519] using an insulation layer [512]. The metal frame [519] itself is a simple frame with 3 holes for the screws.

Notes

I. As stated the main feature of the mechanical frame was to develop a mechanism for moving on the Z-axis. The exact process process for calculating the displacement/ step is as follows

Since the screw moves down by it's pitch for every 360 degrees

$$\frac{pitch}{360} = displacement/degree$$

Each rotation of 360 degrees is done in a certain number of steps via a motor.

$$\frac{360^o}{steps\ for\ 1\ complete\ revolution} \times \frac{pitch}{360^o} = displacement/step$$

Since we also have an acting reduction factor, we get

$$\frac{360^o}{steps\ for\ 1\ complete\ revolution} \times \frac{pitch}{360^o} \times \frac{1}{reduction\ factor} = displacement/step$$

An example displacement/volt is

$$\frac{360^o}{4096} \times \frac{0.7mm}{360^o} \times \frac{1}{30} = 5nm/step$$

Oftentimes, step count won't be given directly. It can however be calculated from by multiplying the steps/rev by the gear ratio. Although this may not always be the case and it is better to depend on the documentation.

Additionally most microcontrollers provide a way to control the motor by the individual step instead of the voltage.

Manufacturing process

I. A metal block is machined with 3 holes in a diagram similar to the notation in [figure 6]. The distance of the front hole [505] from the center of the 2 back holes [503,504] is x mm where x is the reduction factor.
II. Piezo amplifier [502] is machined as given above
III. Screws and bearings [503-508] are purchased from the master cart.
IV. The gears and adapter [513-515,518] can be produced using plastic or metal via 3d printing/metal working
V. Motors, springs/rubber materials [509,510,516,517]can be purchased online.
VI. The dimensions of the bottom frame [519] should be slightly larger (~1cm) to account for space for fitting in the master frame. Otherwise it is a simple machined metal block with holes in the exact same place.
VII. The insulation material [512] applied can be something like rubber tape to avoid conductivity
VIII. The sample holder [511] is just a circular metal cut.

D. Circuit

The circuit contains several components all integrated together to provide precise control over the tip's positioning and the bias voltage applied to the sample. The major elements of the circuit are a preamp, a microcontroller (MCU), op amps, a piezoelectric amplifier, and a bias voltage circuit. The circuit utilized MCU-generated PWM signals, which are used to create analog signals with resistors and capacitors, allowing us to have stable and continuous control over the PNST. The preamp circuit [701] is directly connected to the tip to amplify the weak tunneling current, and this current is then fed into the MCU [702]. Additionally the MCU [702] generates four PWM signals which are used to generate analog signals for continuous operation. The PWM D6 pin generates a signal connected to the bias voltage for the sample. It is further connected to a 10k ohm resistor and a non inverting 2x gain op amp configuration[703]. The added gain helps combat the low power capabilities of the MCU. Similarly, the PWM D9, D10, and D11 circuits connect to non inverting 2x gain op amp configurations to amplify the signals. While the D9 signal is directly fed into the z-axis control of the piezo amplifier[705], the D10 and D11 signals connect to inverting op amps[704] and drive the -x and -y quadrants respectively. These are inverted to generate a negative potential difference at the -x and -y quadrants to contract those sides. The signals are then inverted again and are used to drive the +x and +y quadrants. By using inverting op amps we are able to generate a stronger, more stable signal that can be used to control the quadrants.

Notes

I. The resistors[706] placed between the PWM signals and the electrical components, along with capacitors[706] connected between the PWM signals and ground, are used to integrate the PWM signals, effectively converting them into analog signals. This is crucial for stable and precise control of the piezoelectric actuator.
II. The preamp circuit, located at the tip, acts as a high-gain transimpedance amplifier with a 100Mx gain, converting the small tunneling current (on the magnitude of nA) into a readable voltage (V). This amplified signal is crucial for accurate measurement and analysis in PNST operation.

E. Master Frame

The Master Frame [depicted in figures 8-12] are used to combine all the various parts of the PNST under one portable and compact frame. The very first piece is the lower chamber [figure 8, 805] which simply contains a metal box which is used to hold all the different motorized components like the motors, for the motorized frame and also provides the main structure to the PNST. Furthermore it also contains 4 threaded holes [806] to hold clamps to act as vibrations insulators. Then as seen in [figure 9], the bottom frame sits on top of the lower chamber to seal it and allow for operation of the PNST. Below the lower chamber is the circuitry compartment [figure 10] which is used to house the PCB for MCU and preAmp and 9V batteries [807,808] for the PNST. Then on top of the lower chamber is the acrylic cover [804] as seen in [figure 11]. This lets us see the functioning of the PNST while also acting as a strong shield. If enough vacuum proofing is done, a vacuum chamber can be induced in the PNST. Finally on top is a simple lid [801] for covering up the PNST's top. It is implemented with a simple suction system so that it can be removed easily. Then in [figure 12] is the vibrational chamber system which is meant to isolate vibrations. It is composed of 2 pieces. A large rubber enclosure where the PNST can rest which acts naturally as a vibration isolator. Furthermore it can be connected to the threaded holes using materials with elastic properties such as carbon fiber or springs to keep the system suspended and help isolate unnecessary noise.

Notes

I. The top lid also acts as a faraday cage and prevents unnecessary noise from entering. If required, extra coating can be applied on the acrylic frame and top lid to add greater insulation.

Manufacturing

I. To start with, the PCB [807] can be simply printed and built based on the circuitry while the batteries are 2 rechargeable 9V batteries in a series connection so that the mix terminal becomes ground, negative terminal becomes -9V, and positive terminal becomes +9V.
II. Then metal needs to be simply milled for creating the circuit case and the lower chamber.
III. Within the lower chamber it is necessary to add the threads before installing the internal mechanism.
IV. For the acrylic frame, it can be molded or shaped to form the case.
V. The top lid is again simply milled to act as a lid.
VI. The external rubber frame is made by shaping rubber and molding it to fit our scenario. Furthermore a top metallic/plastic lid can be added on top to make it sturdy and clean
VII. Next the elastic material can be as simple as carbon fiber or spring and be attached directly via a hook to the top of the rubber frame.

F. **Operations**

I. Using the motorized frame, the forescrews and hindscrews are screwed until they reach the tip. Once they are close, after each step, the piezo is extended to check if it has reached the atoms. If not it repeated again to reach within the range of the piezoelectric. [Figure 13]
II. Next the tip is used to scan the current of the atom through quantum tunneling. [Figure 14]

III. This current is then forwarded back to the preamplifier and processed by the MCU and computer. [Figure 16]
IV. Depending on the feedback, the PNST piezo actuator is used to move the tip in the X,Y,Z axis. [Figure 4]
V. This continues in a raster scan approach where the PNST records the voltage at every atom
VI. The recorded voltage is then used to generate a topographical map showing the surface of the atom.
VII. This lets us see the various atomic patterns as well as trends like ravines and elongations. [Figure 15]

Example Embodiments

The main application of the invention is to be used in household and lower-level educational facilities to supplement experimental concepts that may require the capabilities of a full STM but cannot afford or facilitate the purchase and/or installation of such a large scale contraption. Due to the incredibly low cost, portability, and ease of use of the invention, we are able to find usages for the invention in areas that previous iterations of STMs are not able to reach. Lab environments in schools, community colleges, and homes can all benefit from having the capabilities of an STM without the necessity of a bulky and expensive tool.

Objects and Advantages

Unlike traditional industry oriented microscopes, my PNST has been designed by keeping customer needs in mind. Accordingly, a customer would require a lower power, but simpler tool for their needs. The driving mechanism of the PNST takes a cheaper piezo amp based driving mechanism commonly found in DIY of the STM, but consolidates the different parts together under a smaller form factor while maintaining portability features to create an easy to use tabletop version. Furthermore thanks to the cheaper driving mechanism, we are able to achieve a low cost while producing relevant results.

Diagrams

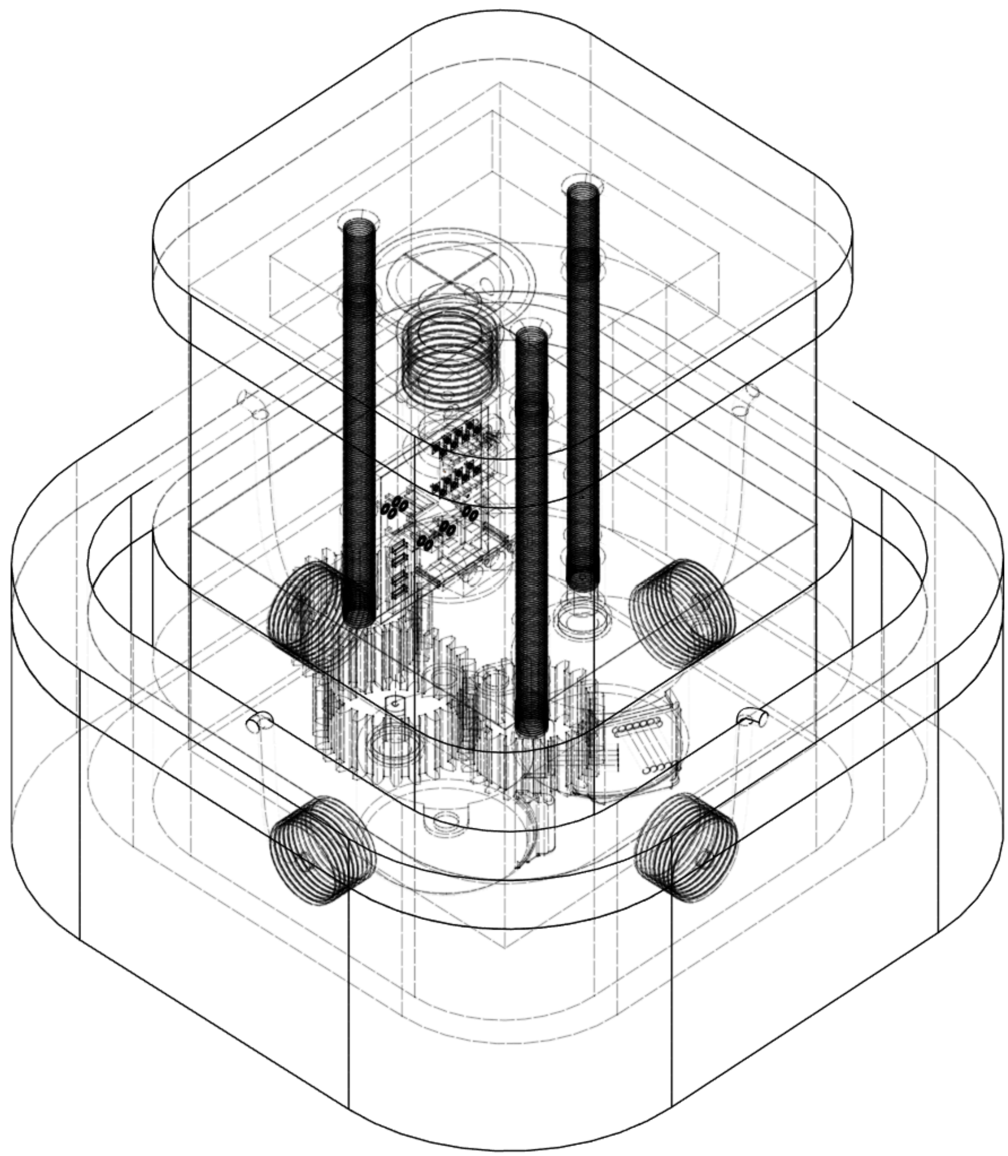

Figure 1: Shaded view of the PNST

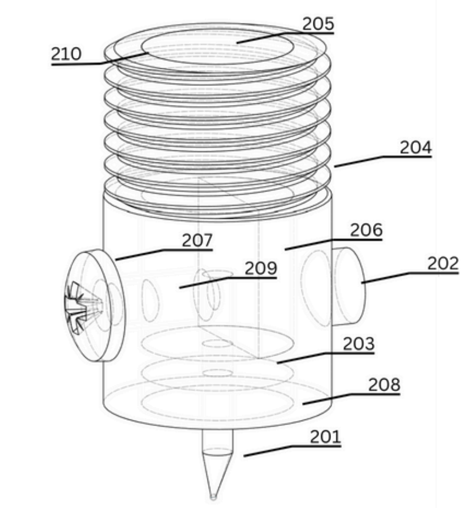

Figure 2: Shaded view of the Tip Holder

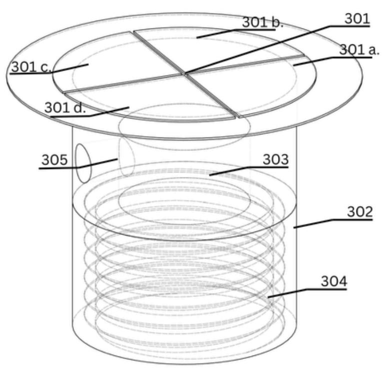

Figure 3: Shaded view of the piezo amplifier

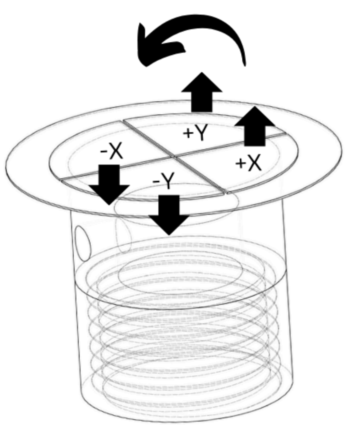

Figure 4: Shaded view of the piezo amplifier moving as a result of piezoelectric effect in the quadrants.

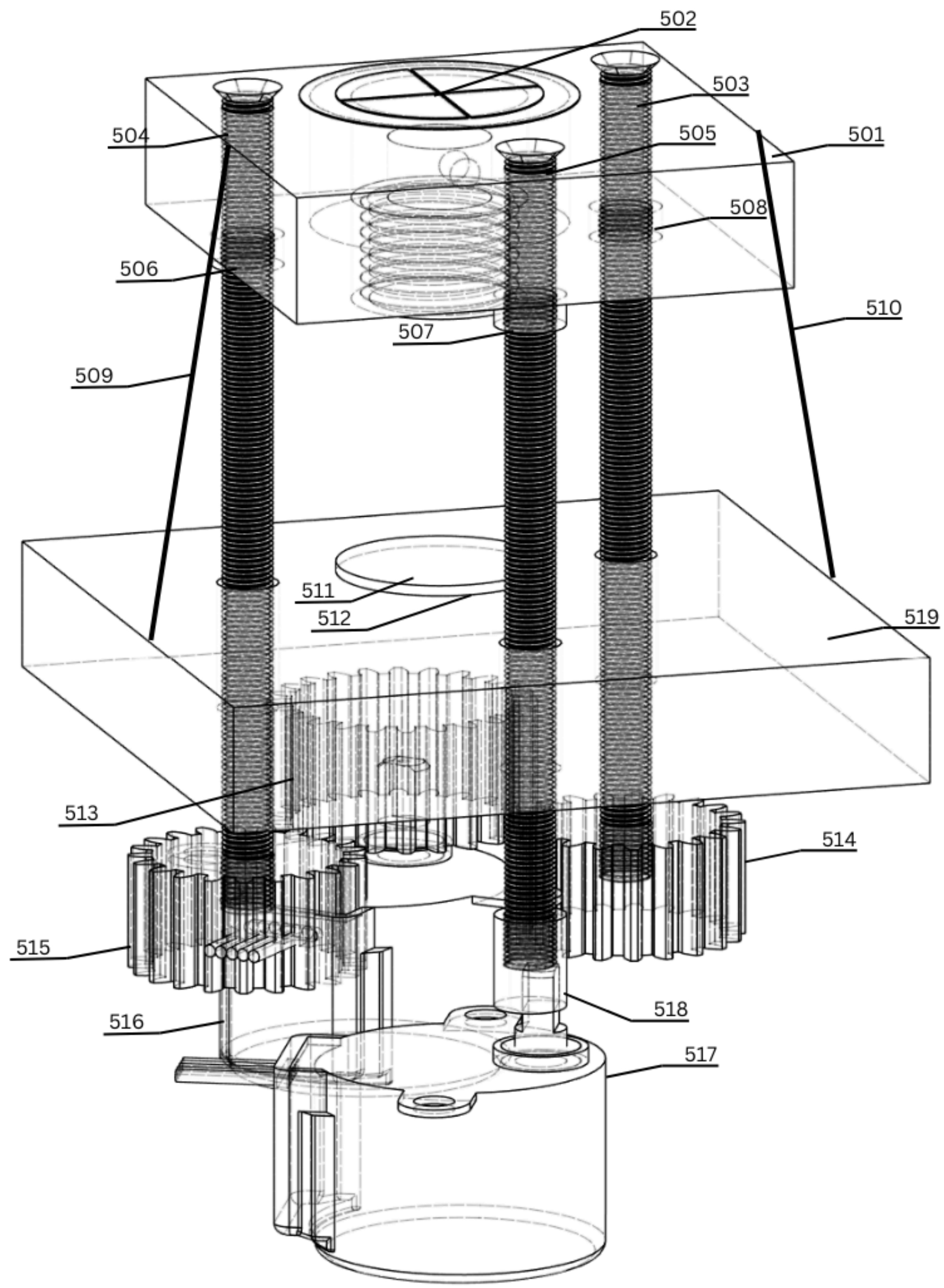

Figure 5: Motorized Stage of the PNST

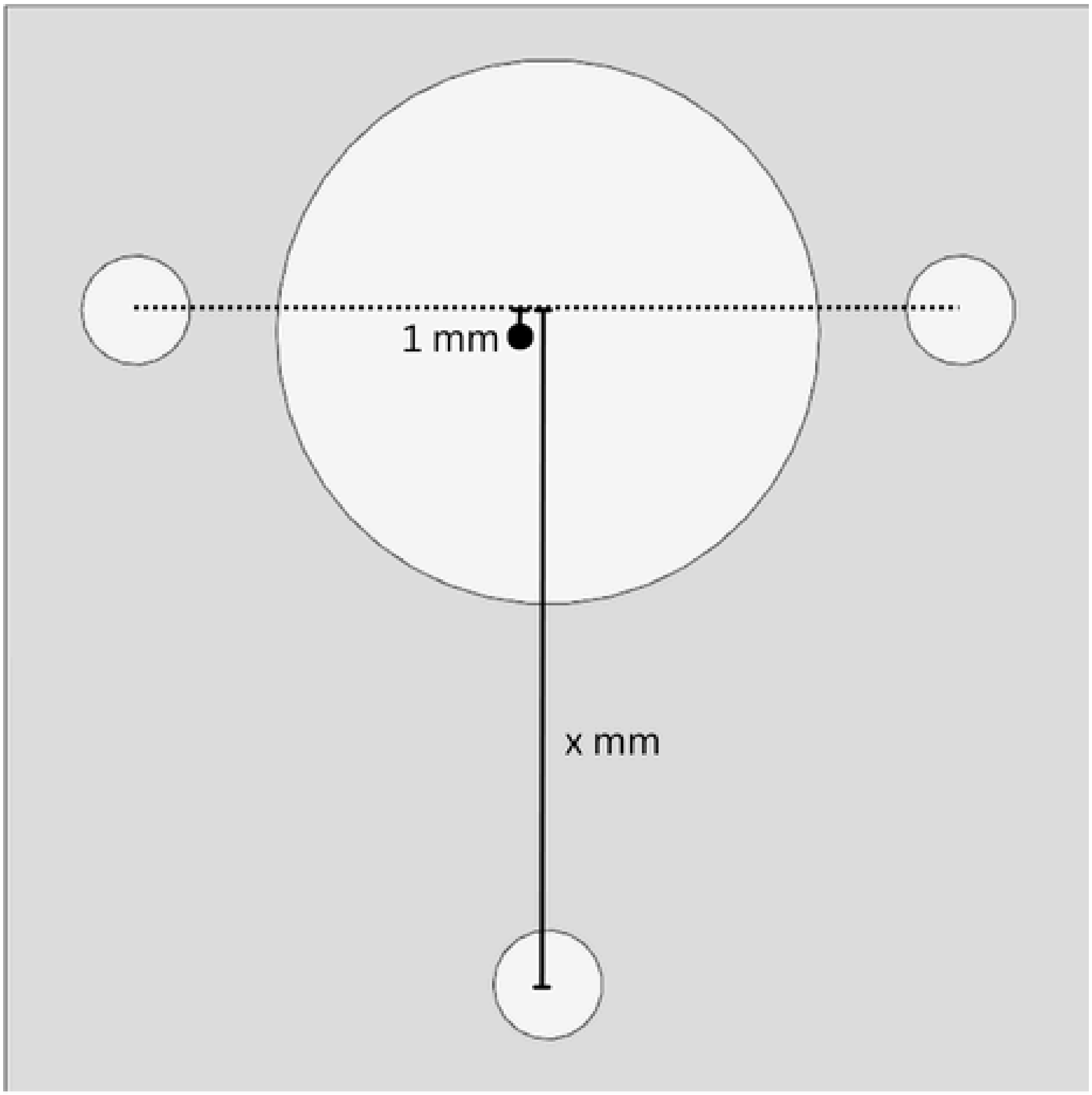

Figure 6: Top mechanical frame

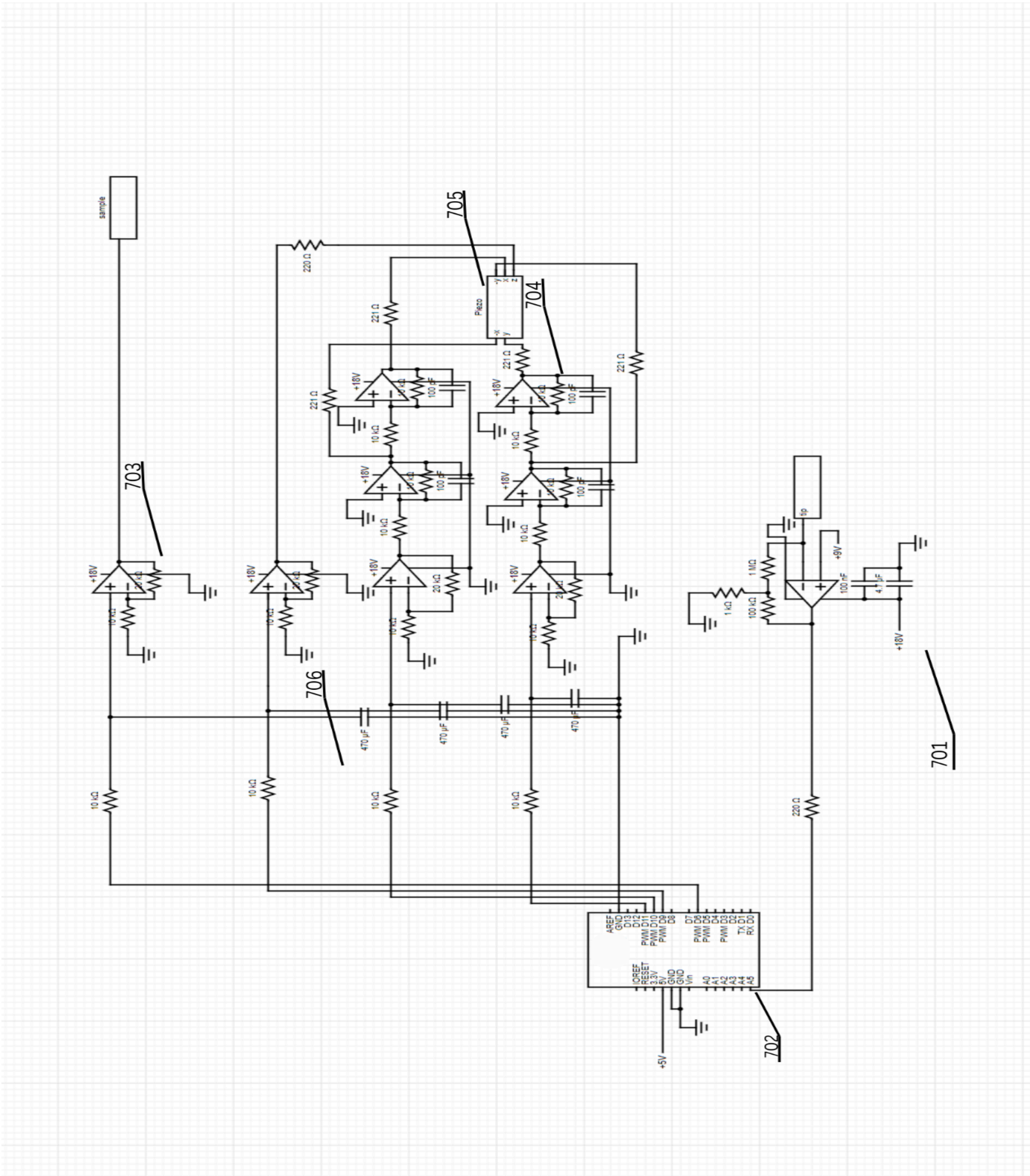

Figure 7: Circuit Diagram

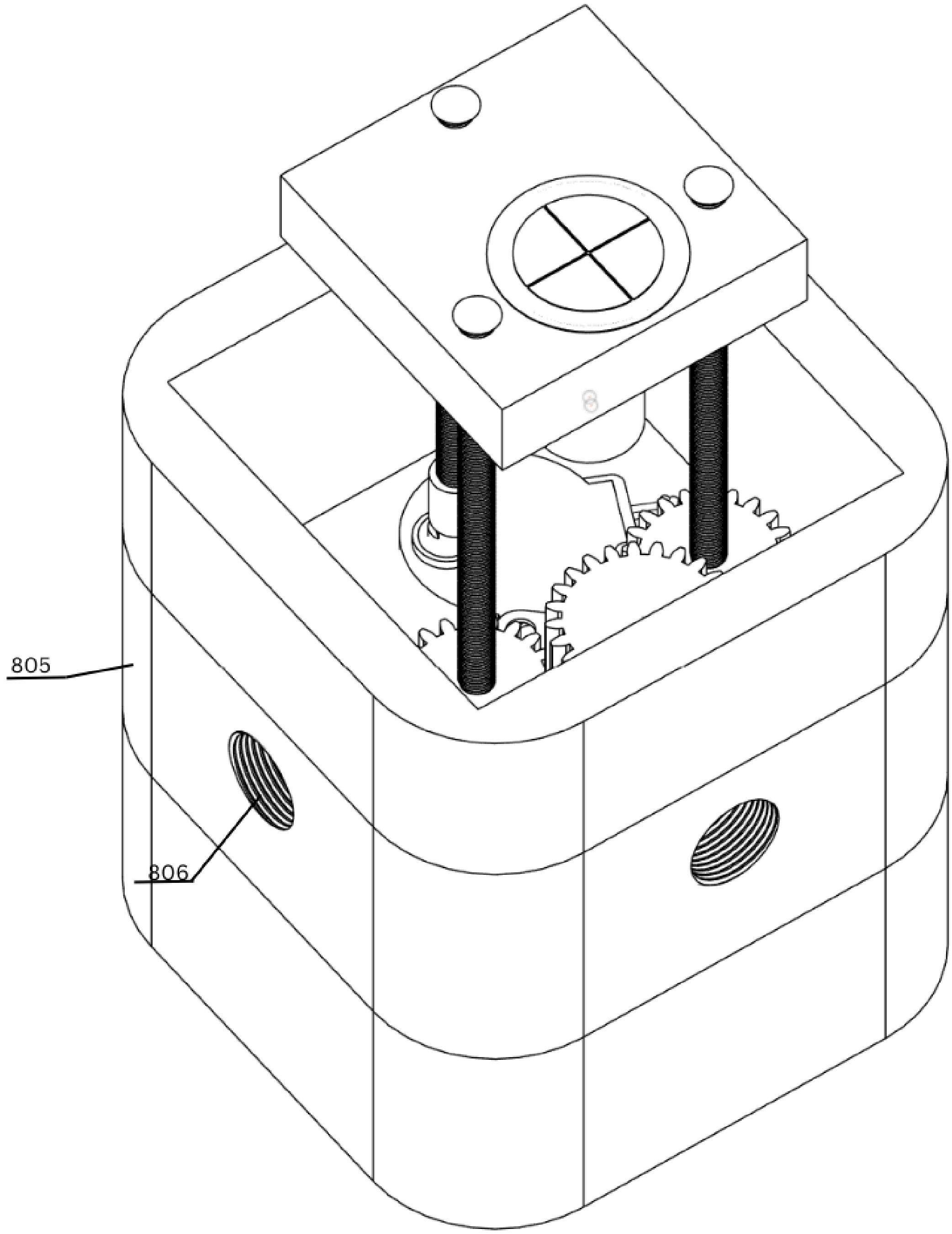

Figure 8: Lower chamber of the PNST with motorized approach

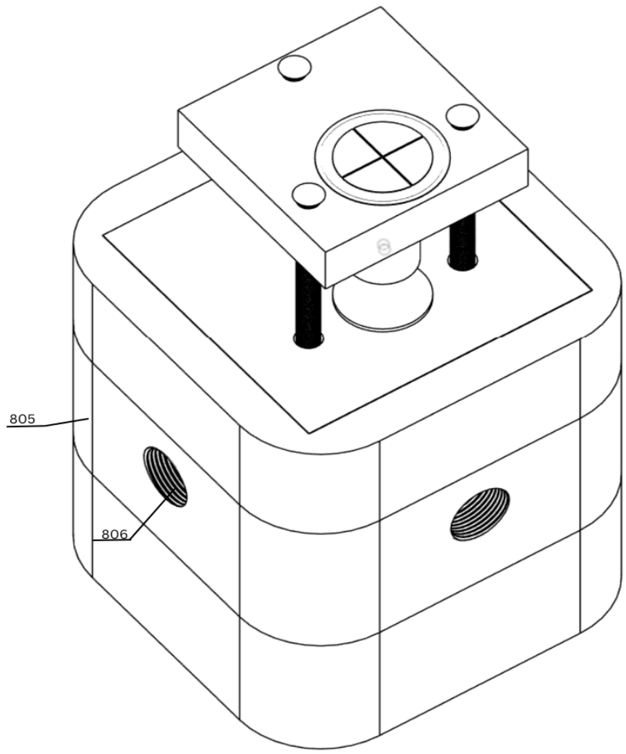

Figure 9: Lower chamber of the PNST with bottom frame

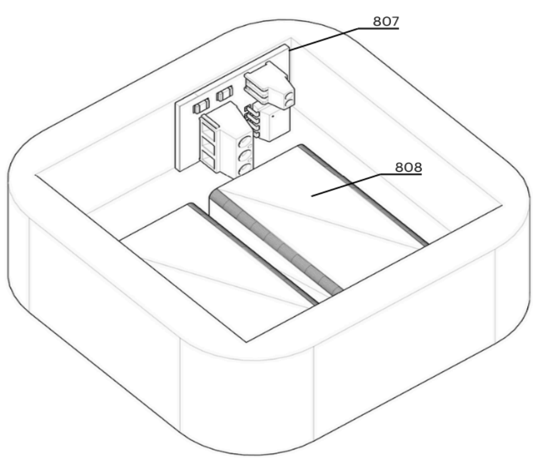

Figure 10: Circuit chamber of the PNST

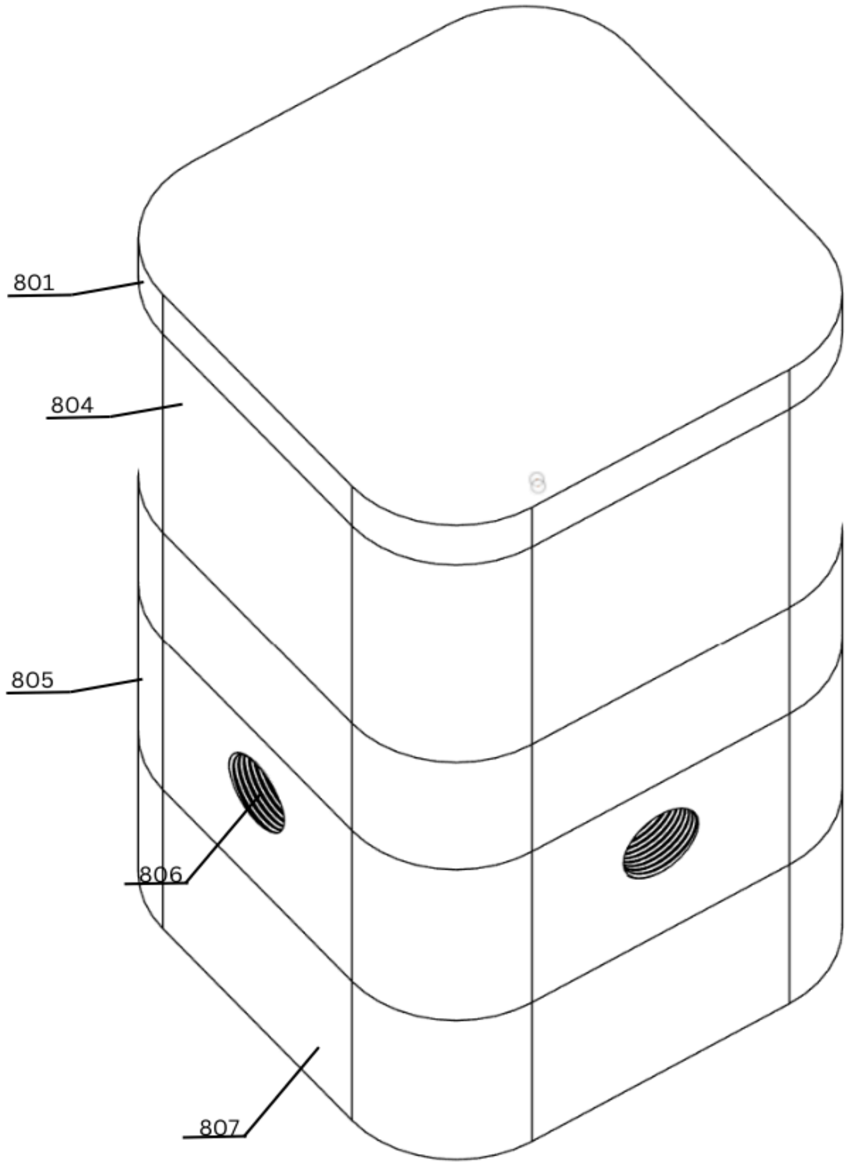

Figure 11: Complete PNST without Vibrational chamber

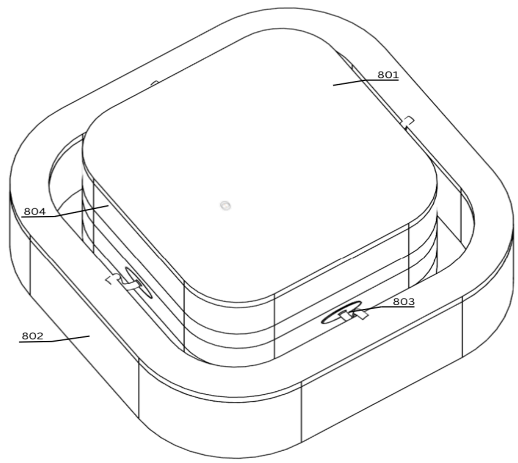

Figure 12: PNST in the vibrational chamber.

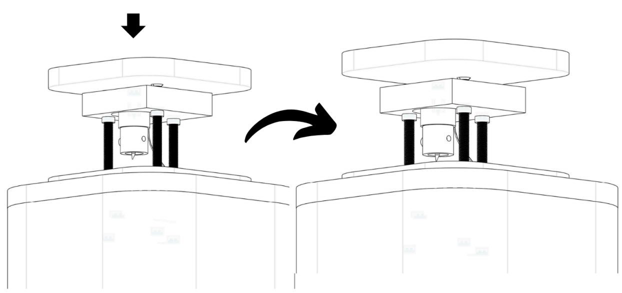

Figure 13: Movement of the PNST tip using motorized frame and piezo amplifier

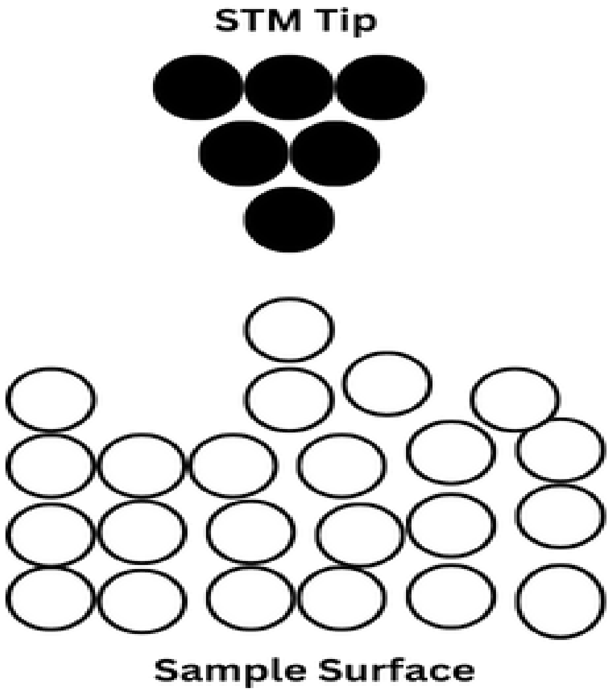

Figure 14: Scanning using tip and exhibiting quantum tunneling

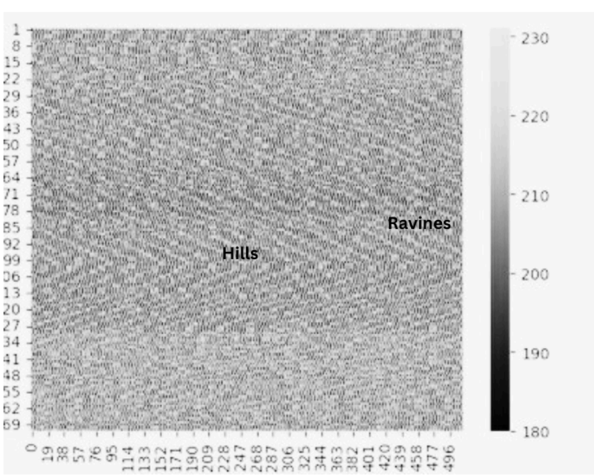

Figure 15: Ravines and Hills

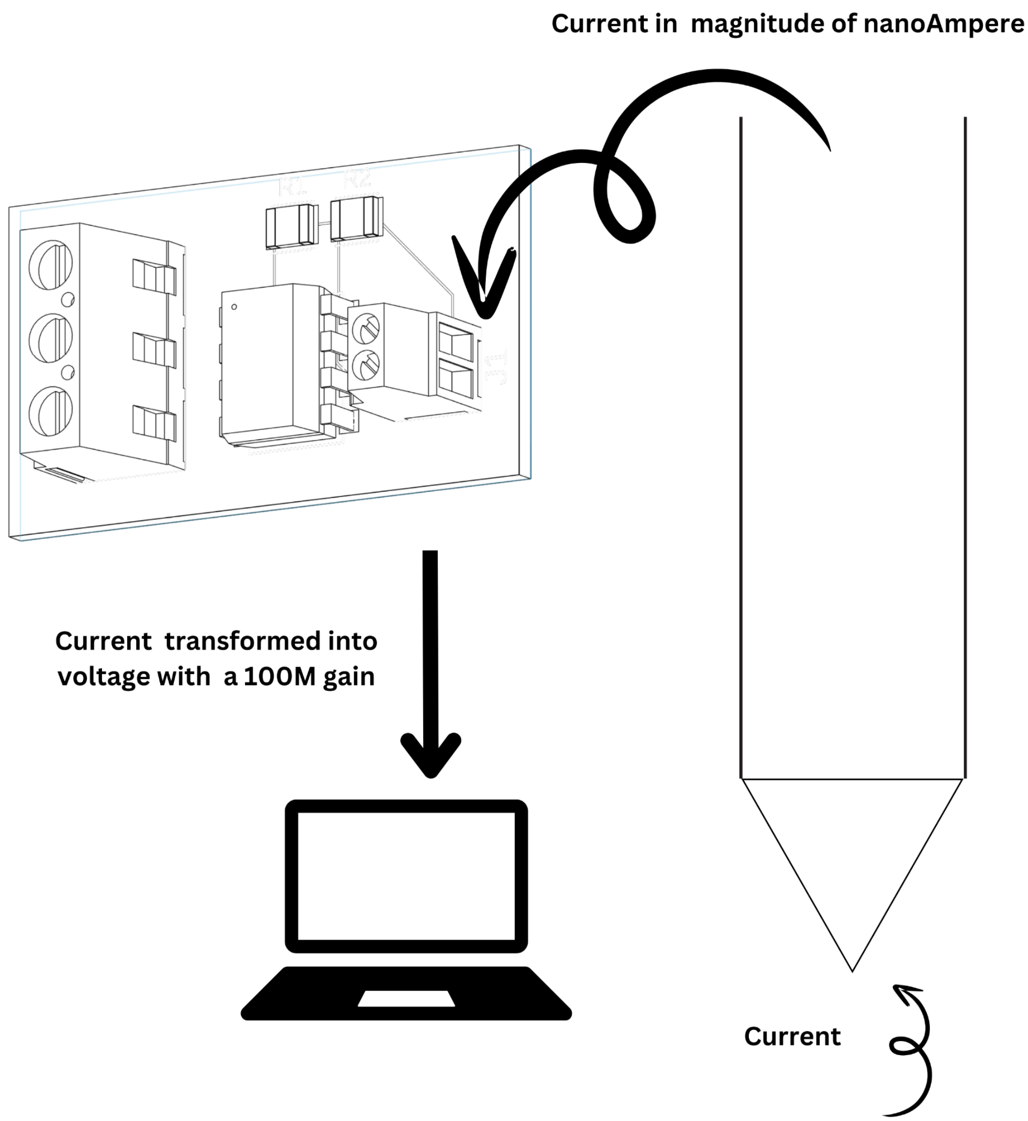

Figure 16: Turning current into voltage

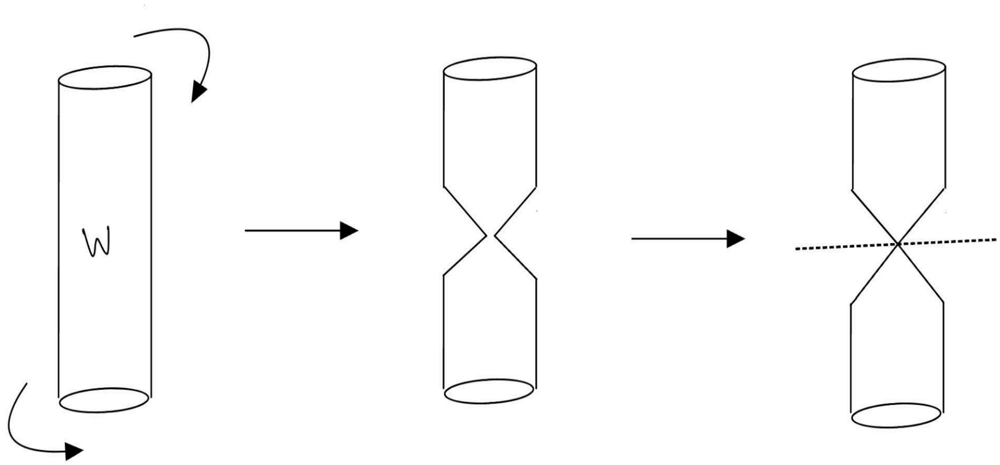

Figure 17: Using torsional twisting effect to create a tungsten tip with diameter 1-20 mm

Pictures of the Functional Prototype

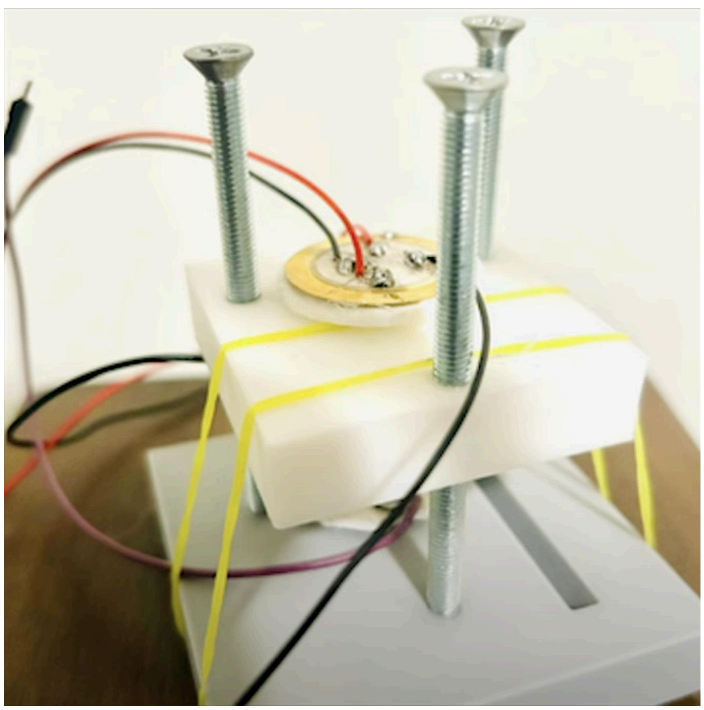

Figure 18: Prototype of the PNST

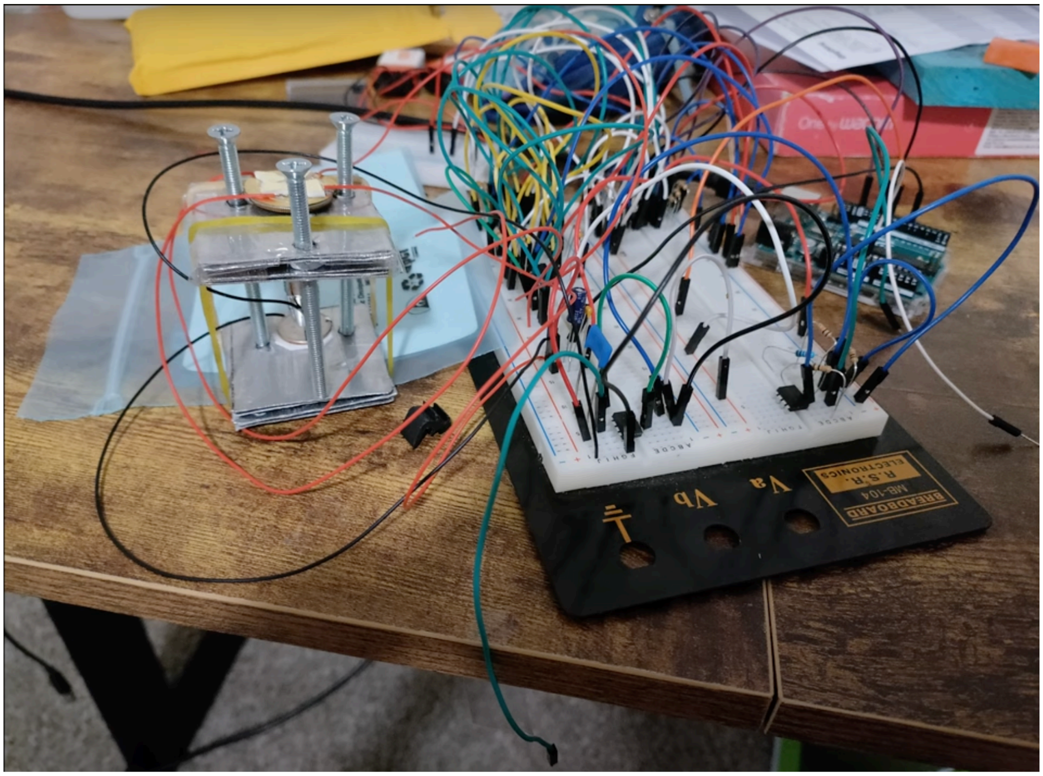

Figure 19: Built-out circuit alongside the PNST