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# Magnetodeposited Nickel on Cu Substrate with the Angle Variation of Magnetic Field

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**ABSTRACT**

The performance of a thin layer of Cu/Ni as a cryogenic sensor is produced by electroplating at various angles with the aid of a 200G parallel magnetic field. Liquid nitrogen ($LN_2$) is a low-temperature medium with temperatures varying from 0ºC to -200ºC. The characterization includes the sensor voltage range, sensor resistance, and sensor sensitivity. Thermocouple TCA-BTA -200ºC to 1400ºC is used as a temperature calibrator. The results showed that all sensors could measure the $LN_2$ temperature in the range of 20ºC to -200ºC corresponds to the thermocouple's ability to measure up to -200ºC. Each sensor has its advantages, but the sensor produced from coating each 3 minutes sample with an angle of 90º has the largest output voltage range up to 0.058 V, and the coating at an angle of 0º with the sensitivity level as a function of $T$ is $S(T) = 0.0051 - 0.002T$, while the 3 minutes coating sensor with an angle of 60º has the smallest voltage range of 0.0439 V and sensitivity (1.88 ± 0.05) V/ºC.



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## I. Introduction

The use of sensors is needed in almost all fields, including medicine [1], computer technology [2], and smoke detectors [3]. The development of sensor technology in health, agriculture, education, military, and civil engineering, is still ongoing. One sensor that continues to be developed is a low-temperature sensor [4], [5]. Research to find variants of low-temperature sensors has also been widely carried out. The need for low-temperature storage units below -150ºC (cryonic temperature) is required for food preservation, organ storage [6], [7], and storage of cow semen for artificial insemination [8]–[10].

A thermometer measuring low temperature is also needed in line with the need for a low-temperature sensor. The characteristics of a low-temperature thermometer are different from room temperature or high-temperature thermometers because they include two things, namely changes in material properties when exposed to temperatures, especially low temperatures, and the design of the sensor material. One of the sensors that can be used is a Resistance Temperature Detector (RTD). RTD sensor materials are generally made of metal in a coil, a thin layer, or thin-film [11], [12]. The working principle of RTD is utilizing resistance changes influenced by temperature [13], [14].

Some materials often used as temperature sensors are Pt, Cu, Ni, Co and their combinations [15]. One of the good metal materials used in manufacturing thin films on RTD elements is platinum (Pt) because platinum has oxidation resistance, high accuracy, and good stability [16], [17]. However, platinum is a metal that is quite expensive. Therefore, to make a thin layer on RTD, other alternatives are used, namely copper (Cu) and Nickel (Ni) [18]–[20].

Cu has the potential to be a temperature sensor [21], but Cu is still less sensitive to temperature changes. This is because the resistivity possessed by Cu tends to be very low [22], as well as the nature of Cu, which is easily oxidized. Therefore, the sensitivity of Cu can be increased by synthesizing it with Ni, which has better resistivity to form a thin layer of Cu/Ni. Another advantage of Ni is that it can attract dissimilar molecules better than Pt, making film deposition easier [23]. Likewise, thin films were chosen because thermocouples have a limited ability to measure temperatures [24] to about -200ºC.

Previous research on Cu/Ni thin films as low-temperature sensors produced by electroplating at various coating times assisted by a 200G magnetic field in the transverse direction to the Cu surface. The coating time varies from 0 to 45 seconds. Liquid nitrogen ($LN_2$) from 0°C to -200°C was used as the low-temperature medium under test. Characterization was carried out on the voltage and sensitivity range. The Cu/Ni sensor of the coating in the 25 s time range has the largest voltage range of 128.48 mV and has a sensitivity (S) which has a linear relationship with temperature ($T$) according to S($T$) = 0.287 - 0.002$T$ [25].

Several attempts to reduce hysteresis are carried out with the help of the use of a magnetic field (B) in the direction parallel to the ion current during coating, which is known as PPMF (Permanent Perpendicular Magnetic Field) [26]. The interaction between Ni ions moving in the electrolyte towards the cathode under the intensity of the magnetic flux will cause a Lorentz effect which can deviate Ni ions from the original direction, which is perpendicular to B, and the velocity of the Ni ion. By attaching the electrodes to a distance of about 4 cm, it is hoped that the Lorentz effect will only produce an oblique path to the Ni ion. This effect can improve the morphology of the Ni layer attached to the Cu substrate [27], [28] so that it is possible to obtain a homogeneous layer, having a denser and more regular arrangement of Ni atoms, capable of filling the porosity of the layer which is microscopically invisible from the surface of the media and appears only in an oblique direction. Also, using magnetic fields during the plating process can increase ionic currents [29], [30], thus speeding up the coating process [31].

In fact, in the use of this magnetic field, as stated by Yue [32], there are several other forces involved besides the Lorentz force (FL), namely the electrokinetic force (FE), the magnetic field force (FB), the magnetic damping force (FD) and the paramagnetic force (FP). The five forces compete with each other depending on the intensity of the magnetic field. The field intensity is not that big, and only two forces play an important role, namely FL and FE. Too large a magnetic intensity will reduce the thickness of the layer and limit the current density [33], [34].

Therefore, this study used the magnetic field intensity of 200G and variations of the coating angle from $0^o$, $30^o$, $60^o$, and $90^o$ to produce variations in Ni thickness. The layer thickness and the microscopic structural conditions of the deposit will play a role in determining the quality of the low-temperature sensor.

## II. Theory

### Magneto Hydro Dynamics (MHD)

MHD is a process of ion movement in an electrolyte solution due to an external magnetic field. MHD combines elements of electromagnetism and fluid mechanics to describe the electrical flow of liquids. Convection of MHD is considered one of the characteristic phenomena in the magneto-electrochemical process. Five magnetic forces occur, namely the paramagnetic force, field gradient force, Lorentz force, magnetic damping force, and electrokinetic force. In this experiment, the force studied is the Lorentz force. Convection is induced by electromagnetic interactions (Lorentz force). Convection can increase the ionic mass transfer rate to increase the coating current. The direction of the magnetic field related to the electric field in the electroplating process is the current efficiency, composition, and layer morphology. The mass transport is increased, thereby changing the electroplating layer [35]. Also, the Lorentz force can affect the surface layer morphology and the thickness of the layer.

### Electroplating

Electroplating or electroplating is a process of coating/depositing a desired protective metal on top of other metals using electrolysis. The provision of direct current into the solution causes a reduction process at the cathode and anode. Faraday's Law of electrolysis serves as the foundation for the electroplating process. The thickness of the produced layer can be estimated if there is a difference in the sample's mass after and before electroplating [36].

### Sensitivity.

Sensitivity is the ratio between the output signal (sensor response) and the input change (measured variable). The sensitivity indicates the temperature sensor's sensitivity to the quantity being measured. Some temperature sensors can have a sensitivity expressed in volts per °C (V/°C), which means that a one-degree change in temperature at the input results in a change in voltage of several volts at the output. If the response is linear, then the sensitivity is the same for the entire measurement range.

### Voltage Range.

One of the criteria for selecting a sensor is the ability or range to respond as needed. The sensor has a wider range, and it can be said that it performs better. A temperature sensor with a wider range can be used to measure the temperature range over a large range.

### Resistivity

Resistivity ($\rho$) is the ability of a material or medium to inhibit its electric current. The resistivity value for each type of metal is different depending on several things such as porosity, constituent minerals, permeability, etc. Resistivityassociated with electrons in electric current by the microscopic structure of the material.


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## III. Method

### Material

Specifications for coating conditions are given in Table 1.

### Substrate Preparation

At this stage, copper and nickel plates are prepared (10 × 1.3 $cm^2$), and the lithography design uses a cutting sticker, $FeCl_3$, and acetone. The copper plates are cleaned by rubbing the surface with an autosomal metal polish in the same direction. The next step is to print the lithography design on the substrate by dissolving it with $FeCl_3$ for about 10 hours and cleaning it with acetone. After the printed design is cleaned by rubbing the surface with autosomal metal polish and smoothing the surface with toothpaste in the same direction, then rinsing with distilled water and alcohol in an ultrasonic cleaner. Then the substrate is dried with a hairdryer and stored by wrapping it on a tissue, placing it on a plastic clip, and then storing it in the dry box.

### Preparation of Cu/Ni Coating

Before plating is carried out, a nickel solution (watt's nickel) is prepared to consist of $NiSO_4$ 260 g, $NiCl_2$ 60 g, $H_3BO_3$ 40g, and $H_2O$ 1000 mL. The ingredients are stirred using a magnetic stirrer for 3 hours. Cu plates as substrate were weighed using Ohaus-PA214 balance and recorded as $M_{Cu}$. A Cu plate is attached to the cathode and a Ni plate to the anode at a distance of 4 cm. Electroplating is carried out at a voltage of 4.5 V by varying the coating angle of $0^o$, $30^o$, $60^o$, and $90^o$; the electrolyte temperature is $60^oC$, for 3 minutes. A 200G magnetic field is installed in a direction parallel to the direction of the electric field. After finishing, the sample is removed, then rinsed with distilled water and dried using a hairdryer. After drying, the sample was weighed again and recorded as $M_{Cu/Ni}$.

### Experimental design

The experiments were carried out according to the procedure, as shown in Figure 1. Liquid nitrogen is a low-temperature medium ($LN_2$) [37]. This medium is filled in a 10 liters volume container where the temperature can be varied from 0°C to -200°C based on the location of the depth in the container. Locations close to the container lid have a higher temperature than those close to the bottom of the container. $LN_2$ temperature near the cover 20°C. Characterization of the sensor following the standard test of immersion in liquid or gas [38]. To avoid the effect of leakage of voltage on the connecting cable between the sensor and the VP-BTA voltage probe, the sensor is composed of a transducer circuit [39]. Then the Cu/Ni sensor and the TCA-BTA thermocouple as a calibrator were slowly put into the container. Slow motion on the sensor is intended so that the sensor can measure in an orderly manner any moderate temperature changes. The output of the Cu/Ni sensor is in the form of voltage and time data, while the thermocouple output is in the form of temperature and time data. Both of these outputs can be observed on a computer screen with the help of Mini Labquest and Loggerpro 3.8.6, two software in the numeric and graphic display. Furthermore, the data is then analyzed on the sensor voltage range, resistance, and sensitivity [40].

**Table 1.** Specifications in the electroplating process

| **Specifications in the electroplating process** | |
|---|---|
| Cathode | : Cu |
| Anode | : Ni |
| Electrode spacing | : 4 cm |
| Electrolyte | : H3BO3 (40 gr), NiSO4 (260 gr), NiCl2 (60 gr), and H2O (1000 ml). |
| Electrolyte temperature | : 60?C |
| Deposition time | : 3 minutes |
| Transverse magnetic field | : 200 G. |
| Cu / Ni film specifications | |
| Long | : 15.40 cm |
| Wide | : 2 mm |
| Big | : 7.61 cm |
| Form | : square wave |
| Cu layer thickness | : 17 ?m |
| Ni layer thickness | : (27.09 - 149.44) ?m |


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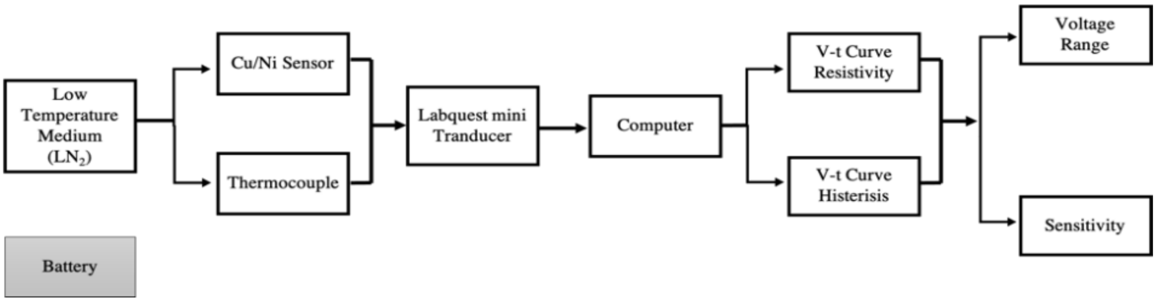


**Figure 1.** Schematic of low-temperature sensor performance research Cu/Ni

## IV. Results and Discussion

### Resistance

Figure 2 shows the response of the Cu/Ni sensor to the temperature of liquid nitrogen when the temperature is lowered from 20ºC to -200ºC and then increased to 20ºC again. In general, the output voltage signal still contains ripples. This is related to the microscopic structure of the Cu/Ni sensor when an electric current is applied. For a fine layer with a regular crystal structure and uniform grain size, an electric current can smoothly pass through the coating surface so that the output signal is smooth. However, for the Cu/Ni layer, which has a coarse microstructure, irregular crystal structure, and non-uniform grain size, the electric current will encounter many constraints resulting in ripples in the output signal.

Another thing that can be seen in Figure 3 is the shape of the curve, which is gentle at the top and steep at the bottom. This is related to different responses to changes in temperature. Likewise, the position of the peaks projected on the *x*-axis looks different. This shows the variation in the time it takes for the sensor to reach a temperature of -200ºC. From the data (V, t) and (T, t) as the logger pro output, especially for the temperature drop, it is possible to create a VT curve where the slope curve shows the sensitivity of the sensor in responding to temperature changes.

Furthermore, the sensitivity was analyzed from the temperature-slope (VT) curve. The VT curve is not linear, so the data (V,T) are assigned according to the order of the polynomial 2. Sensitivity (*S*) is determined by the slope of the dV/dT curve. Here, because the sensitivity still depends on the temperature, but for the curve *V*(T), a larger slope indicates that the sensor is more sensitive. Stability is obtained from the relative sensitivity error.

### Voltage Range

The voltage range is the difference in the minimum output voltage when the sensor measures the lowest $LN_2$ temperature ($V_{-200^oC}$) to the maximum output voltage when the sensor measures $LN_2$ 20ºC ($V_{-20^oC}$) temperature. $V_{-20^oC}$ is obtained when the sensor is placed near the mouth of the container, while $V_{-200^oC}$ is obtained when the sensor is placed on the surface of the $LN_2$ in the container. The variation of each sensor's highest and lowest voltage shows

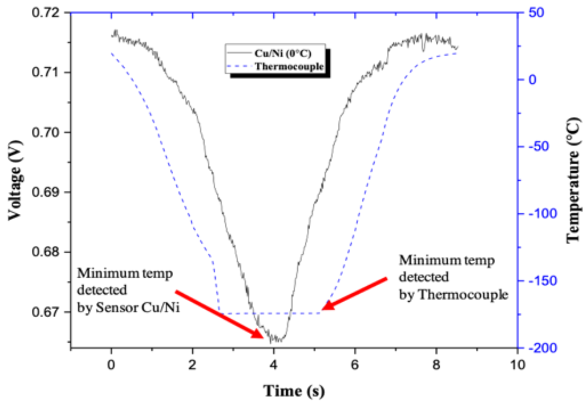


**Figure 2**. Cu/Ni sensor response

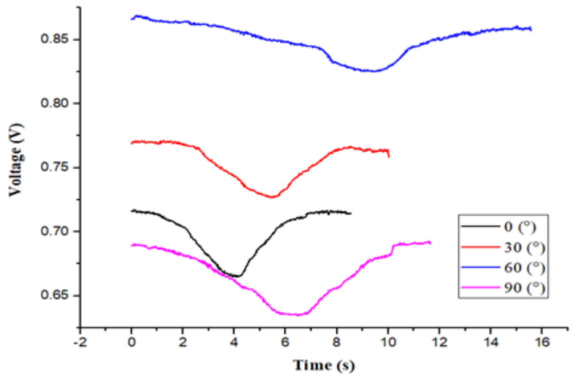


**Figure 3.** The response of the Cu/Ni sensor to the decrease and increase in temperature of $LN_2$

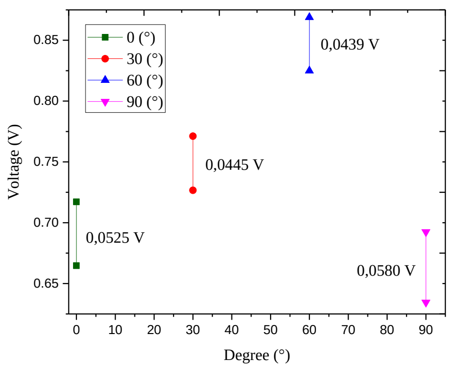


**Figure 4.** Cu/Ni sensor output voltage range in response to $LN_2$ temperature


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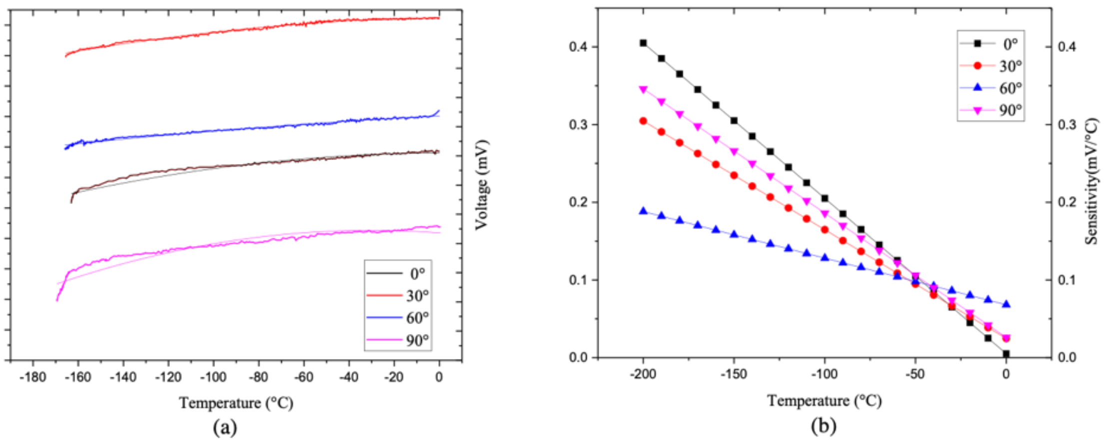


**Figure 5.** (a) Sensor sensitivity and (b) Cu/Ni sensor sensitivity level

the amount of Cu/Ni sensor resistance as a function of temperature T.

From here, the sensor from the coating at a 90° angle has the lowest $V_{-200oC}$ compared to other sensors at 0.69 V, while the largest voltage is 0.87 V corresponds to the coating sensor at a 60°. The difference between the highest and lowest voltage is the voltage range. The large voltage range makes the sensor more accurate at displaying moderate temperatures. The largest voltage range of 0.058 V corresponds to the sensor resulting from a 3 minutes deposition at 90°.

### Sensor sensitivity

Figure 5 shows a voltage-temperature curve. Sensitivity can be seen from the slope of the curve, which shows the change in the output voltage to changes in $LN_2$ temperature. The VT curve for all sensors tends to be curved so that the sensitivity is different at each temperature.

Mathematically, the equation for the VT curve can be approximated by a polynomial of second-order [25].

$$V = b_0 + b_1 T + b_2 T^2 \quad (1)$$

while sensor sensitivity is a derivative of voltage to temperature.

$$\kappa(T) = \frac{dV}{dT} = b_1 + 2b_2 T \quad (2)$$

The adjustable sensitivity curve from -200°C to 0°C is shown in Figure 5. From this figure, it can be seen that the lower the medium temperature, the sensor sensitivity increases. Thus, it can be concluded that the Cu/Ni sensor is more suitable for use as a low-temperature sensor. For example, a sensor that results from coating at an angle of 60° has a sensitivity of 0.128 V/°C at -100°C, whereas when used at -200°C, the sensitivity increases to 0.188 V/°C. Also, the sensor resulting from coating at an angle of 0° has the highest slope compared to other sensors, so even though it has varying sensitivity levels, the lower the temperature, the more sensitive it is. At -100°C the sensitivity is 0.205 V/°C while at -200°C the sensitivity rises to 0.405 V/°C. The sensitivity of this sensor is two times increased from the sensitivity of the sensor from coating at an angle of 60°, whereas when compared to the sensor resulting from a 60° coating, when it is used to measure a temperature of -200°C, the sensor from the coating at an angle of 0° has a sensitivity of 2.2 times almost 2.5 times. Therefore, sensors from 0° plating are suitable for selecting low-temperature sensors. About eq. (2) then, this sensitivity level can be expressed as

$$\kappa(T) = -1.21 - 0.012T \text{ (V/°C)} \quad (3)$$

Regarding the stability of the sensor in measuring temperature, all sensors have a stable voltage signal in response to changes in temperature. This quantization is indicated by an index of terms greater than 0.97.

## V. Conclusion

From this research, it can be concluded that all sensors have been able to display their response as a temperature sensor from 20°C to -200°C. The coating sensor at an angle of 90°C has the largest voltage range, namely 0.058 V. Furthermore, the sensitivity of the sensor in responding to temperature varies and is proportional to moderate temperature, while the sensor from 0° angle coating results is the most sensitive compared to other sensors, namely (0.405 ± 0.03) V/°C. Using a magnetic field during coating has increased the sensor's sensitivity.

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## Declarations

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| **Author contribution** | **:** | Moh. Toifur was responsible for the entire research project. He also led the writing of the manuscript and the collaboration with the other authors. Effilia Allun Jaladri, Efi Kurniasari, Yuni Latifah, and M. Taufiqurrahman participated in the data collection and analysis. All authors approved the final manuscript. |
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