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Research Paper

The Effect of Electrolyte Concentration on The Sensitivity of Low-Temperature Sensor Performance of Cu/Ni Film

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Abstract
The purpose of this research is to make a low-temperature sensor with copper and nickel material or Cu/Ni film. The Cu/Ni film sensor is made by an electroplating method assisted by an external magnetic field of 200 G which is installed parallel to the deposition current. The Cu/Ni film is made by varying the concentration of the electrolyte solution. Next, the Cu/Ni film that was made was tested on LN2 medium to measure its sensitivity value in response to changes in temperature. The results showed that the Cu/Ni film sensor could detect changes in LN2 temperature. The results of data analysis showed that the curve relationship between voltage and temperature in the sample with the 2nd concentration state (C2) had the highest relationship to influence each other between the voltage and temperature variables, and the sample had the highest sensitivity value compared to the others.

Keywords
Electrolyte Concentration, Sensitivity, Low-Temperature Sensor, Cu/Ni Film, Liquid Nitrogen, Magnetic Field.

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1. INTRODUCTION

The National Research Master Plan has 10 strategic areas including food preservation namely in the 2015-2019 Food Industry No. 3 namely Preservation Technology (freezing, drying, preserving with sugar/salt) (RIRN 2017-2045) in order to increase Indonesia's fresh food export commodities so it is needed the development of cryogenic-based food preservation methods (Khadatkar et al., 2004; Goswami, 2010). Increased export-import activities on fresh food commodities in the international market led to the idea of developing new technology in the form of cryogenic freezers using liquid nitrogen (LN2) called Cryofreezing.

The development of the curing method using liquid nitrogen media requires a tool that is able to detect changes in low temperature in LN2 storage flasks. One type of low-temperature sensor that can be used is an RTD-based temperature sensor (Fraden, 2010; Chowdhury and Bulbul, 2010; Blasdel et al., 2015). The economical RTD sensor has been developed by Toifur et al. (2019, 2020) and Khusnani et al. (2019) with copper and nickel or Cu/Ni film. The results of the study stated that the weakness of this sensor is the response time to slow temperatures for temperatures below -150 °C while for temperatures above -150 °C the temperature response is fast. This is thought to be caused by the non-uniform surface morphology of the Ni deposit because there is no conditioning of Ni ions when diffusing onto the Cu surface. The result of this is that the level of regularity of the Ni crystal structure is inconsistent following changes in deposition parameter settings.

The addition of magnetic fields aims to improve the morphological uniformity of Ni deposits (Yu et al., 2013; Zieliński et al., 2015). The role of parallel magnetic fields in the electrodeposition process is to form a regular pattern of Ni particle distribution on the substrate (Yamada and Asai, 2005). Thus the parallel magnetic field can also affect current efficiency, particle content of the coating, surface morphology, and the properties of the Ni coating (Zhou et al., 2013; Fattahi and Bahrololoom, 2015), increasing the mass transfer of metal ions significantly. The use of parallel fields is to magnetize electrolyte solutions. Decreased viscosity of electrolyte solutions and growth of hydrogen gas (Wu et al., 2014; Kumar and Sahoo, 2012), and increase the thickness of the coating structure (Jabbar et al., 2017). From these two aspects (parallel magnetic fields and electrolyte solution concentrations) it will produce a dense and homogeneous morphological structure of the layer.

Based on this, this study aims to make the Cu/Ni film assisted by a magnetic field parallel to the electrolyte concentration solution varied. The layer that has been obtained is then tested for its performance as a low-temperature sensor to see the sensitivity value of the sensor in response to changes in temperature.

2. EXPERIMENTAL SECTION

2.1 Materials

The Cu/Ni Film is made using the electroplating method. The materials used are copper (Cu) and nickel (Ni) plates of size (10 x 1.3) cm which are placed as cathodes and anodes. The electrolyte solution used in the deposition process consists of a mixture of H_3BO_3, $NiSO_4$, $NiCl_2$, and H_2O, with the composition listed in Table 1. The deposition process is carried out using an external magnetic field of 200 G, which is mounted parallel to the deposition current.

Table 1. The concentration of electrolyte solution

Conc.	H_3BO_3 (g)	$NiSO_4$ (g)	$NiCl_2$ (g)	H_2O (mL)
C1	30	225	40	1000
C2	33	255	45	1000
C3	36	285	50	1000

2.2 Methods

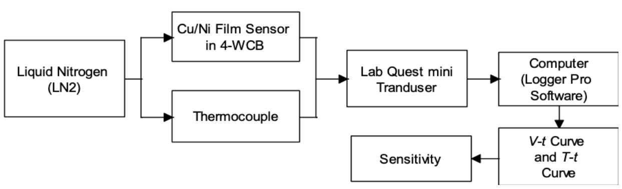

Figure 1. Flow-chart on the performance of Cu/Ni Film low-temperature sensor

The Cu/Ni film that has been formed, is tested for its performance as a low-temperature sensor to determine the sensitivity value of the sensor according to Figure 1. The sensor performance testing is carried out in liquid nitrogen with a temperature range between 0 °C to -170 °C by inserting the sensor slowly into the flask with a speed of 0.2 cm/s. Nitrogen flasks contain 10 liters of liquid nitrogen with a temperature difference between the top and the bottom. The output data is displayed in the form of an output voltage at various temperatures. This voltage varies depending on the temperature of the medium. Voltage variations occur due to changes in sensor resistance values. The temperature of the medium varies according to the depth of the flask. Voltage V and temperature T have a relationship:

$$V = aT^2 + bT + c \tag{1}$$

The relationship between the two variables V and T can be seen through the index of determination, R^2 (Toifur et al., 2014; Khusnani et al., 2019).

3. RESULTS AND DISCUSSION

The results of data retrieval are shown in Figure 2.

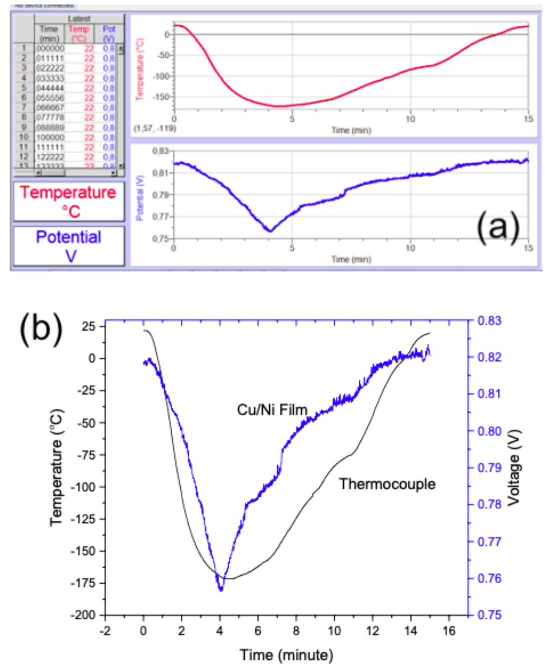

Figure 2. (a). The Data logger pro and (b). Time, voltage and temperature data on sensor performance measurement with voltage output data as data from Cu/Ni film sensors for samples with deposition at concentration 1 (C1)

Figure 2a displays a sample graph or Logger Pro data output for measuring low temperatures with thermocouple and Cu/Ni film sensors tested together in liquid nitrogen medium. Whereas in Figure 2b, the graph shows the relationship between voltage and temperature and time of the data in Figure 2a. Based on these results, it was concluded that the Cu/Ni film or the resulting Cu/Ni film sensor was able to respond to changes in temperature from liquid nitrogen.

Figure 2. a. The Data logger pro and b. Time, voltage and temperature data on sensor performance measurement with voltage output data as data from Cu/Ni film sensors for samples with deposition at concentration 1 (C1)

By observing Figure 2b, information can be obtained that the response of the two sensors between the thermocouple and the Cu/Ni film sensor is different. The Cu/Ni film sensor can respond to temperatures lower than the thermocouple which can detect changes in temperature up to > -170 °C and more quickly respond to changes in temperature rise between -170 °C to 20 °C. However, in response to changes in temperature from the range of 20 °C up to -170 °C, the response of Cu/Ni film sensors tends to be slower than thermocouple, this is because in that temperature range the thermocouple is more able to capture changes in temperature than the Cu/Ni film sensor.

The voltage, temperature and time data that have been obtained are then analyzed to find out the relationship between the voltage curve and the temperature of the sensor produced. The curve relationship is obtained by taking data from the range

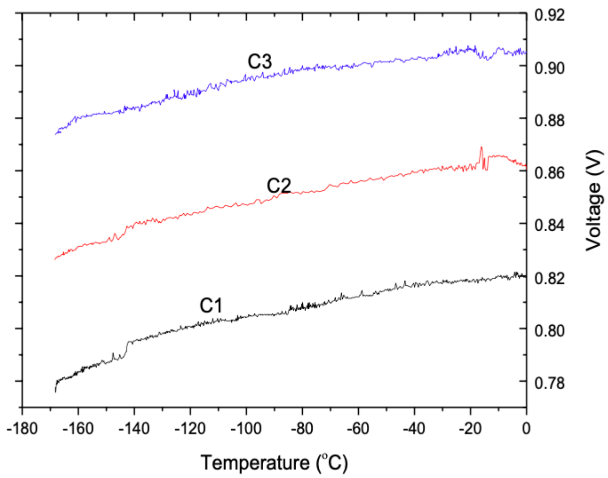

Figure 3. The output voltage and from the Cu/Ni film sample at changes in liquid nitrogen temperature from -170 °C - 0 °C.

-170 °C to 0 °C, as shown in Figure 3. The data is then processed using equation (1) so that the equation values obtained in table 2. Table 2 displays the coefficient values of a, b, c and the index of determination from the graph of the relationship between voltage and temperature.

Table 2. 2nd order polynomial fitting for each concentration

Conc.	2nd order polynomial fitting, V=aT2+bT+c	Index of determination, R^2
C1	V = -0,0012T2 + 0,0296T + 819,24	0,985
C2	V = -0,0008T2 + 0,0840T + 764,74	0,988
C3	V = -0,0009T2 + 0,0182T + 829,05	0,987

Based on the results of the 2nd order polynomial fitting, information can be obtained that is, the relationship between the voltage and temperature curves for the overall determination index value indicates a value exceeding 0.95. Based on this, both temperature stresses have a strong or mutually influential relationship (Rao et al., 2016b,a). The determination index value of the three samples is known that C2 has the highest value compared to the others with a value of 0.988. These results indicate that by giving effect to the amount of concentration with C2 levels, it gives a better relationship between stress and temperature than others.

The reliability of the sensor can be seen from the linearity and sensitivity (Toifur et al., 2020). Figure 4a shows a linearity graph between voltage and temperature. The slope of the linearity graph shows that the greater the slope obtained, the sensor in response to changes in temperature is more sensitive (Rao et al., 2016b,a). Based on this, it can be seen that the highest linearity is obtained by C2 and the lowest is obtained for C3. As for the sensitivity value shown in Figure 4b, where the highest sensitivity is owned by C2 with a value of 0.084 mV/°C and the lowest is obtained by the Cu/Ni film sensor for C3 with a value of 0.018 mV/°C.

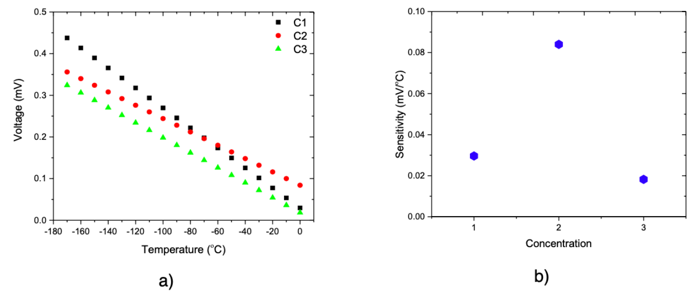

Figure 4. (a). linearity graph and (b) Sensitivity values for Cu/Ni film sensors on changes in liquid nitrogen temperature from -170 °C to 0 °C

The difference in yield at each concentration can be made possible due to the content of the material given in the manufacture of different electrolyte solutions. Basically, every material in an electrolyte solution has different benefits, where $NiSO_4$ acts as the main source of nickel ions, $NiCl_2$ has a role to help corrosion and increase the diffusion coefficient of nickel ions, while H_3BO_3 as a buffer (Birlik and Azem, 2018; Bouhidel and Rumeau, 2000; Budi et al., 2019). In this study, the amount of content of each ingredient made increases from C1 to C3 (according to table 1), but H_2O is made constant so that the most distinguishing of the three is the thickness of the mixture of these ingredients. The high amount of concentration or concentration of the material mixture shows that the amount of nickel ion availability is large (Schlesinger and Paunovic, 2011), by giving the effect of an external magnetic field parallel to the deposition current with a large magnetic field value that continues to influence the rate of Ni ions to the cathode which is different, this is because the dominant influence lies in the amount of ion content from each applied concentration.

4. CONCLUSIONS

Based on the research results obtained information that RTD-based sensors or Cu/Ni film sensors can detect changes in low temperature on LN2. The response of Cu / Ni film sensors is lower than that of thermocouple, whereas, for the rising temperature the opposite applies, the Cu/Ni film sensor is faster in responding to changes in rising temperature. The relationship between the voltage and temperature curve obtained that the sample with the state C2 has the highest relationship to influence each other between the voltage and temperature variables, and the sample has the highest sensitivity and the highest linearity compared to the others.

5. ACKNOWLEDGEMENT

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