Pressure Transducer with Au–Ni Thin-Film Strain Gauges

K. Rajanna, S. Mohan, M. M. Nayak, N. Gunasekaran, and A. E. Muthunayagam

Abstract—**The behavior of a pressure transducer with Au–Ni (89 : 11) film as strain gauges have been studied. The effects of post-deposition heat treatment on the resistance of the thin-film strain gauges and hence the output performance of the pressure transducer are discussed. The effect of a repeated number of pressure cycles carried out over a period of eight months has also been reported. The maximum nonlinearity and the hysteresis is improved from 0.92% FSO to 0.06% FSO after 1000 pressure cycles. The output behavior of the pressure transducer with temperature has also been studied.**

I. Introduction

PRESSURE transducers are basically electromechanical devices used for a variety of applications. The primary function of the pressure transducer is to sense fluid pressure and provide an electrical output proportional to the input pressure. A pressure transducer essentially consists of a diaphragm which undergoes deformation due to applied pressure. This mechanical deformation of the diaphragm in converted into an electrical response by a strain gauge bonded to it. It was more common to use foil-type strain gauges for this purpose. However, in recent years, the use of thin-film strain gauges as sensors in pressure transducers has gained importance due to their numerous merits. The distinct advantages are absence of adhesive material, flexibility to tailor the properties of the sensing film, etc. Although several investigations on the strain sensitivity of different metal [1]–[16] and alloy films [17]–[19] have been reported, the publications on the utility of these films as strain gauges in devices such as pressure transducers are few.

In the present paper we report the study of a pressure transducer with Au–Ni (89 : 11) alloy thin-film strain gauges with a meandering path pattern [15].

The starting material for fabrication was Au–Ni (82 : 18), a high-temperature brazing alloy with a unique characteristic, namely, its liquid and solid temperatures are the same (950°C). Although this alloy is being used for brazing of stainless-steel foils, it is found to have very good adhesion and corrosion resistance properties [20]. In view of these and since no study of this alloy with respect to strain gauges has been reported, an attempt to explore its suitability and applicability for thin-film strain gauge application has been made in the present work.

II. Experimentation

In the present work an integrated diaphragm assembly has been employed. A special feature of this diaphragm design is the incorporation of a strain-relieving cavity to take care of the strain due to mechanical handling, mounting, or assembly process. The material used for the fabrication of the pressure transducer is precipitately hardened X17U4 steel. Further, details including the dimensions of the diaphragm assembly and the information on diaphragm surface preparation are given in our earlier publication [21]. Before depositing the sensing film (strain gauges), the insulating films consisting of alternate layers of Al_2O_3 and SiO_2 were deposited on the diaphragm surface using reactive electron beam evaporation technique. The diaphragm assembly was maintained at 200°C during deposition. The need to deposit insulating oxide layers, the deposition process details, and the necessity to have multilayers instead of single-layer oxide films have already been described by Rajanna *et al* [21].

After the deposition of the insulating oxide layers, copper contact pad films and interconnecting copper pad films of thickness greater than 3000 Å were deposited. Subsequently, Au–Ni film (strain gauge film) was deposited. The Au–Ni (82 : 18) material in the form of wire (obtained from Wilkinson Company, USA) was evaporated from a molybdenum boat. It is believed that since gold and nickel possess nearly the same vapor pressures at a given temperature, the possibility of fractionization of this alloy during evaporation is much smaller. In order to minimize the possibility of fractionization, a shutter was placed above the source during initial heating of the boat. The shutter was removed only when the boat temperature was sufficiently high to evaporate both the constituents of the alloy. The boat temperature during the evaporation was close to 1200°C. The analysis of the deposited film by plasma emission spectrometry technique revealed the Au–Ni composition as 89.2% : 10.8%. This deviation in composition from starting material is attributed to the fact that single-source evaporation of a composite containing two or more components results in incongruent evaporation

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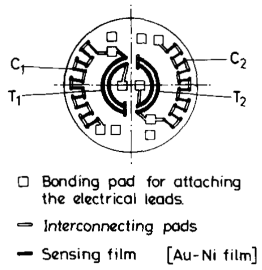

Fig. 1. Thin-film strain gauge pattern deposited on the pressure transducer diaphragm.

[22]. The thickness of the Au–Ni film (650 Å) during deposition was measured and later compared using a multiple beam interferometer. Prior to deposition of copper and Au–Ni, the substrate was subjected to ionic cleaning for about 10 min. Precision mechanical masks were used while depositing the above films of required pattern. These masks were prepared using a CNC (Computer Numerically Controlled) spark erosion machine with a dimensional tolerance of ±1 μm. The strain-gauge pattern adopted (for the four gauges, as shown in Fig. 1) and their location on the diaphragm are the same as those already reported in our earlier paper [23].

The four gauges were connected in Wheatstone bridge configuration with all active gauges. The gauges experiencing the tensile strain (near the center) are connected in one set of opposite arms and those experiencing the compressive strain (at the diaphragm edge) in the other. It is important to note that the tensile strain causes the resistance of the gauge to increase and compressive strain results in decrease of resistance. The stabilization of the film was carried out by subjecting the diaphragm assembly to post-deposition heat treatment.

The output characteristics of the transducer were studied using a dead weight pressure calibrator (Model 5020 of Desgranges et Huot, France). The details of the procedure followed are given elsewhere [23].

III. Results and Discussion

A. *Effects of Post-Deposition Heat Treatment on the Thin-Film Strain Gauge System*

As can be seen in Table I, the post-deposition heat treatment resulted in a decrease in gauge resistance. The reduction in gauge resistance is attributed to annealing of defects incorporated in the film structure during deposition [24], [25]. It is important to note here that whereas the manganese film pressure transducer [23] had an average reduction of 6.5% in gauge resistance after heat treatment at 120°C, the average reduction achieved in the present Au–Ni film resistance was only 0.29%. Therefore, in order to make sure of the almost complete annealing of defects, the heat treatment process was repeated at 170°C. After the second heat treatment, the average decrease in gauge resistance was 1.36%. However, further heat treatment did not result in any additional decrease in gauge resistance.

TABLE I
Resistance Values of Thin-Film Strain Gauges Deposited on the Pressure Transducer Diaphragm

Details of the Thin-Film Strain Gauges	Resistance Values (Ω) Before Heat Treatment	After Heat Treatment at 120°C for 1 h	After Second Round of Heat Treatment at 170°C for 2 h
Gauges located at the edge of the diaphragm			
gauge C_1	96.58	96.17	94.50
gauge C_2	99.59	99.31	98.23
Gauges located near the center of the diaphragm			
gauge T_1	105.79	105.45	104.68
gauge T_2	104.92	104.78	104.00

The insulation resistance of the oxide layers increased from about 300 to 40 000 MΩ at 10 V dc due to post-deposition heat treatment. The increase in insulation resistance is believed to be due to enhanced oxidation of the individual oxide layers and the formation of stronger interfaces between layers.

B. *Individual Gauge Response*

Figs. 2 and 3 show the variation of relative change in resistance $\Delta R/R$ with pressure for the gauges (T_1 and T_2) located near the center of the diaphragm and those at the edge (C_1 and C_2) after the post-deposition heat treatment. It is observed that for all the gauges, the variation in $\Delta R/R$ with pressure is more linear and repeatable (between gauges) after the heat treatment process when compared to the variation of the same before the heat treatment.

C. *Output Performance of the Thin-Film Pressure Transducer*

The variation in output voltage of the pressure transducer as a function of input pressure is quite linear. The values of non-linearity and hysteresis (in percentage FSO; full scale output) versus pressure (in bars) are shown in Fig. 4. The maximum nonlinearity and hysteresis observed is 0.92% FSO. By considering the resistance of the thin-film strain gauges, the film thickness, the power dissipation factor, etc., the bridge excitation was optimized to 3 V dc. It has been observed that higher excitation voltages showed instability above 1% of FSO in the output of the pressure transducer under zero load condition. This instability at higher excitation voltages is considered to be due to excessive heating of the thin-film strain gauges.

Further, it was found that the nonlinearity and hysteresis improved after 1000 pressure cycles of a nominal pressure of 30 bar for 3-min duration carried out over a period of 8 months. The typical data of maximum nonlinearity and hysteresis observed after 500 cycles is 0.39% FSO. Again the maximum nonlinearity and hysteresis found after additional 500 cycles is 0.06% FSO. This indicates that films require about 1000 cycles to achieve nonlinearity and hysteresis of the order of 0.06%, which

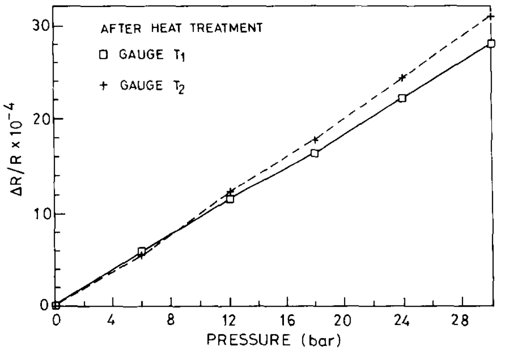

Fig. 2. Variation of relative change in resistance $\Delta R/R$ with pressure for gauges located near the center of the diaphragm—after heat treatment.

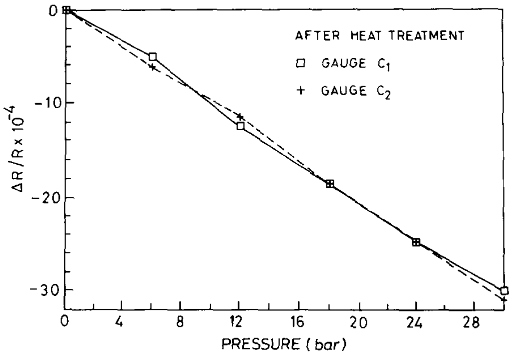

Fig. 3. Variation of relative change in resistance. $\Delta R/R$ with pressure for the gauges located at the edge of the diaphragm—after heat treatment.

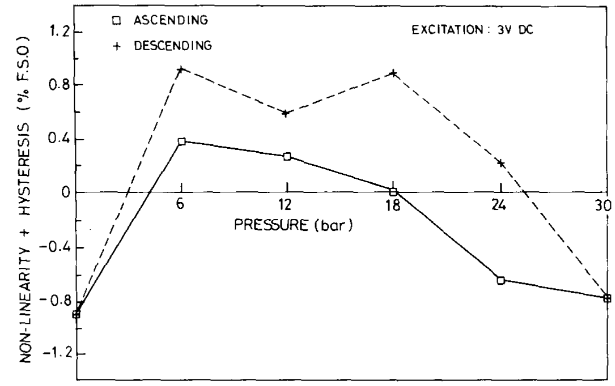

Fig. 4. Nonlinearity and hysteresis versus pressure.

is thought to be due to stress-relieving effects. Similar observation has been reported in the resistance-strain characteristics of metal films by Parker and Krinsky [1].

It has been observed that the FSO, zero-offset plots were linear and parallel with a negative slope of 0.111 mV/°C. Also the net output was found to be linear in the temperature range −20°C to +70°C with a maximum deviation of less than 0.6%.

In comparison with pressure transducer made with Mn film strain gauges [23], the present Au-Ni film strain gauge transducer shows a stability of 0.6% in a time span of 4 months although the gauge resistance is lower and the film thickness is of the order of 650 Å. Also, it has been observed that the Mn film strain gauge transducer inevitably requires an overlayer to avoid atmospheric influence leading to change in resistance and hence output drift with time, whereas, Au-Ni film pressure transducers do not require any overlayer.

IV. CONCLUSIONS

The output performance of a thin-film pressure transducer with Au-Ni film as the strain gauge has been studied with continuous excitation for at least 2 h before taking any output readings. It was found that the optimum bridge excitation was 3 V dc, since higher excitation voltages showed instability above 1% FSO which is thought to be due to excessive self-heating. The maximum nonlinearity and hysteresis observed after 1000 repeated pressure cycles over a period of 8 months was 0.06% FSO. The output behavior of the pressure transducer with temperature was also studied after stabilizing at each temperature for 2 h and it was found that the net output was linear with a maximum deviation of less than 0.6%.

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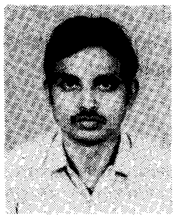

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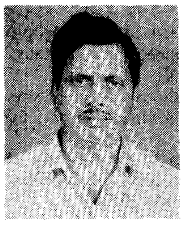

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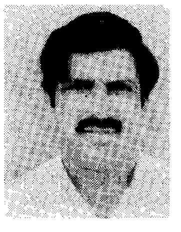

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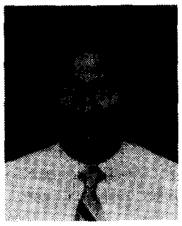

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