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Developing a temperature measuring system model for agriculture dryer with consideration of fringing field effect in mathematical modeling

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ABSTRACT

Thermometer accuracy at small rise in temperature leads to increasing the knowledge about products process especially in drying of plants, fruits and biological laboratories. This developed model a thermometer based on capacitance change resulting from deflection of a bimetal cantilever. The effect of fringing field is included in the model. The deflection of the theoretical model is simulated and results are shown to closely follow the previously published results. Finally, the complete theoretical model, including the effect of fringing field, is simulated using an example. The Taguchi method with analysis of S/N ratio is used to obtain the optimal design of the sensor. Using the optimum settings, the S/N ratio improved by 24.11 dB.

1. Introduction

The accuracy of measuring sensor in agriculture and biological application like thermometer is improved in recent researches (Ezeoha and Ugwuishiwu, 2017). Thermometer accuracy of low temperature leads to increasing the knowledge about products improvement especially in drying of plants, fruits and biological laboratories. Micro Electro Mechanical Systems (MEMS) are often used as sensing devices to measure quantities such as position, acceleration, motion, temperature and pressure. MEMS sensors, typically, sense changes in relative position by means of optical techniques (Faiçal et al., 2017; Zhang and Liao, 2017), changes in the capacitance (Rudolf, 1983), flexing of piezoresistors (Stemme and Stemme, 1990) or changes in the tunneling current (Rugar et al., 1988). Thermometry is one of the fields where MEMS technology is widely used. One of applicable area to use these thermometers is in drying of plants and fruits. Into assess changes in temperature, a fundamental physical quantity, several phenomena or effects may be used. In general, to measure temperature, any quantity that changes as a function of temperature may be used. However, for any particular application, there are additional merits and requirements that determine the effectiveness of particular thermometric quantity. Therefore, one may use sensors based on various physical effects and fabricate them from different materials. To measure very low temperatures, which can used in bio applications, a new type of self-calibrating thermometer that exploits the shot noise in a tunnel junction is developed by Lafe Spietz et al. Their thermometer relates voltage across junction to temperature. This relation is enabled by assumption that electrons in a metal obey Fermi-Dirac statistics and by a relative noise measuremen t with the use of the electron charge (Spietz et al., 2003).

For measurements at low temperatures in bio applications, resistance thermometers are commonly used. These sensors are based on germanium films on gallium arsenide (Boltovets et al., 2003). A multipurpose thermal sensor based on Seebeck effect is designed by Danijela Randjelovic et al. The sensing element of these sensors operates without chopping, cooling systems or external biasing (Randjelović et al., 2008). A thermal-based approach is described by Jacky Chow et al. for in-situ displacement sensing of electro-thermal actuators. Metal MUMPS process is used to monolithically fabricate a device encompassing a thermal sensor and an in-plane electro-thermal actuator (Chow and Lai, 2009). In a research work, the DFM capacitance probes with temperature sensors were evaluated for precision and accuracy (Mjanyelwa et al., 2016).

Because of necessity in aware of the temperature of drying process of the plants, the accuracy of the bimetal MEMS thermometer is very important. In the present study, a bimetallic beam subjected to nonlinear electrostatic pressure as a thermal sensor that can used in dryer of plants, fruits and agricultural products is studied. The model is developed with considering the effect of fringing field. The quantity used to measure the temperature is the capacitance variations due to deflections of bimetallic cantilever beam.

This paper is organized as follows. In Section 2, the physical model of the sensor is proposed. Section 3 covers development of the theoretical model for the bimetallic beam. The effect of pull-in voltage and fringing fields are also investigated. Section 4 provides MATLAB simulation results using a numerical example as well as validation of the deflection model.

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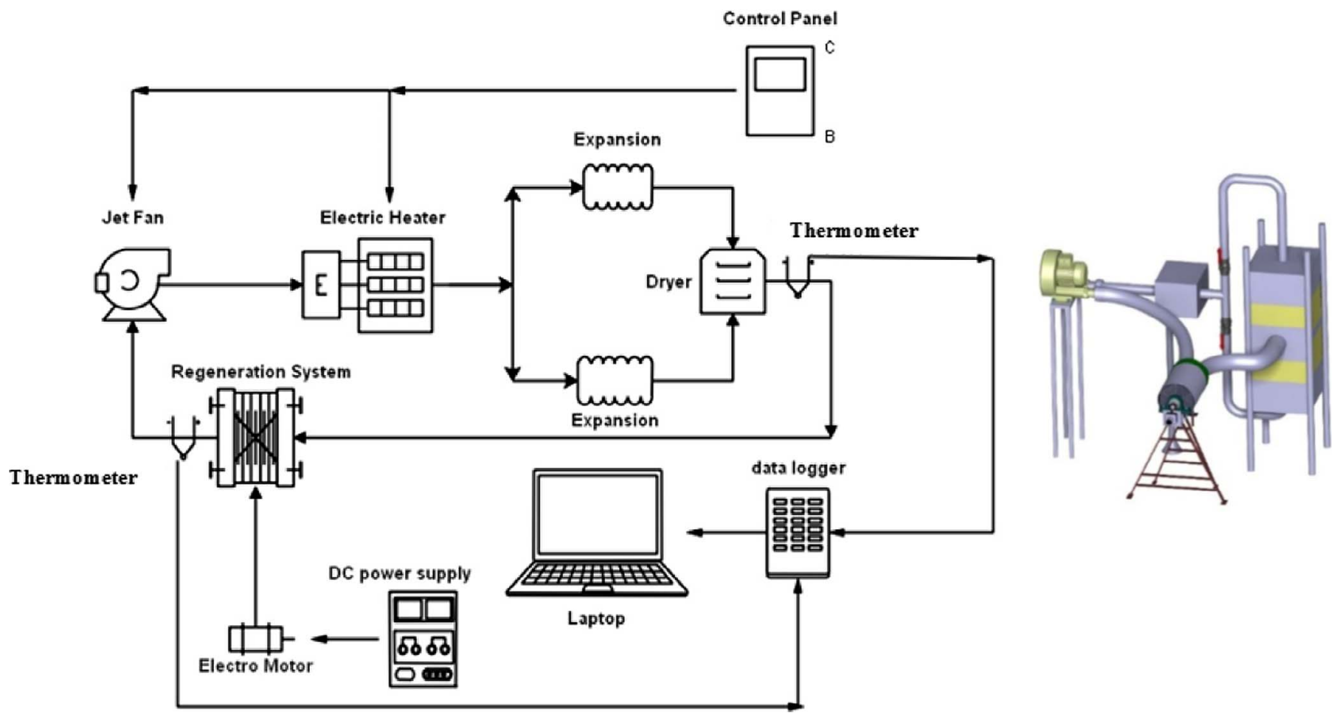

Fig. 1. Schematic illustration of the setup of agriculture dryer with regeneration system and position of thermal sensor.

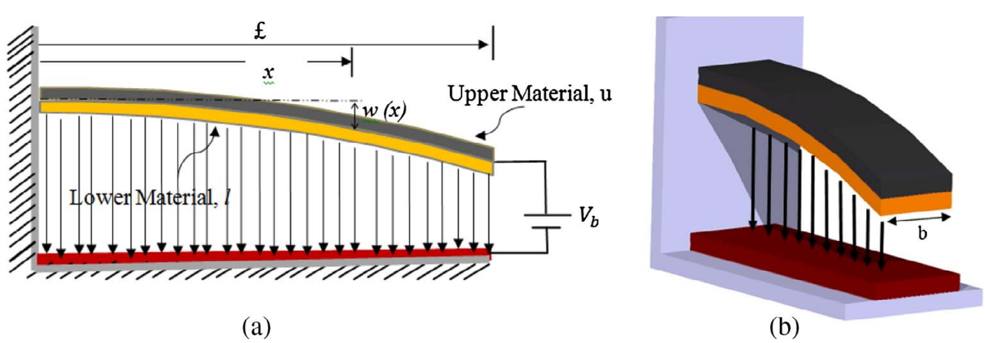

Fig. 2. Schematic of the developed thermal micro sensor.

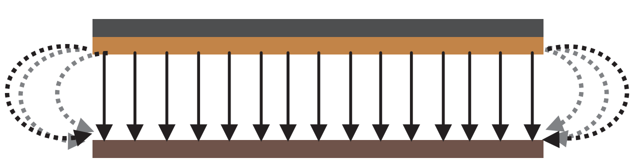

Fig. 3. Effect of fringing field.

Table 1
Design variables used for comparing with Ref. (Hu et al., 2004).

Design variable	Description	Value	Unit
$L_1 = L_2$	Beam length	20	mm
$h_1 = h_2$	Beam thickness	57	µm
$b_1 = b_2$	Beam width	5	mm
g_0	Capacitor initial gap	92	µm
$E_l = E_2$	Young modulus of beam	55.8×10^9	Nm^{-2}
ε_0	Permittivity of air	8.854×10^{-12}	$\frac{c^2}{N.m^2}$

2. Model description

A thermal sensor applicable in agriculture products can use in a dryer to control the temperature of air and time of drying. The position setup of thermal sensor in dryer with regeneration system is shown in Fig. 1.

Table 2
Comparison of calculated tip deflection of developed model with Ref. (Hu et al., 2004).

Bias voltage (V_b)	Tip deflection In developed model (µm)	Analytical Tip deflection Ref.(µm)	Experiment Tip deflection Ref.(µm)	Δ(%) Compare with analytical in Ref.	Δ(%) Compare with experiment in Ref.
20	89.23	90.2	90.5	1.08	1.40
40	83.63	84.3	84.6	0.79	1.14
60	70.66	71.5	70.0	1.17	0.94
65	64.06	67.2	64.0	4.67	0.1
67	59.93	65	59.0	7.80	1.57

A simplified model of the developed bimetallic thermal micro sensor is shown in Fig. 2a. It consists of a bimetallic cantilever micro beam separated from a fixed ground plate as a substrate by an air gap. There is a bias voltage between the capacitor electrodes. Because of the difference in coefficients of thermal expansion in bimetal materials, changes in environmental temperature results in deflection of the cantilever beam. The beam deflection causes a change in the gap between the capacitor plates and thereby affects the value of the system capacitance. Therefore, the influence of temperature on the capacitance can be measured.