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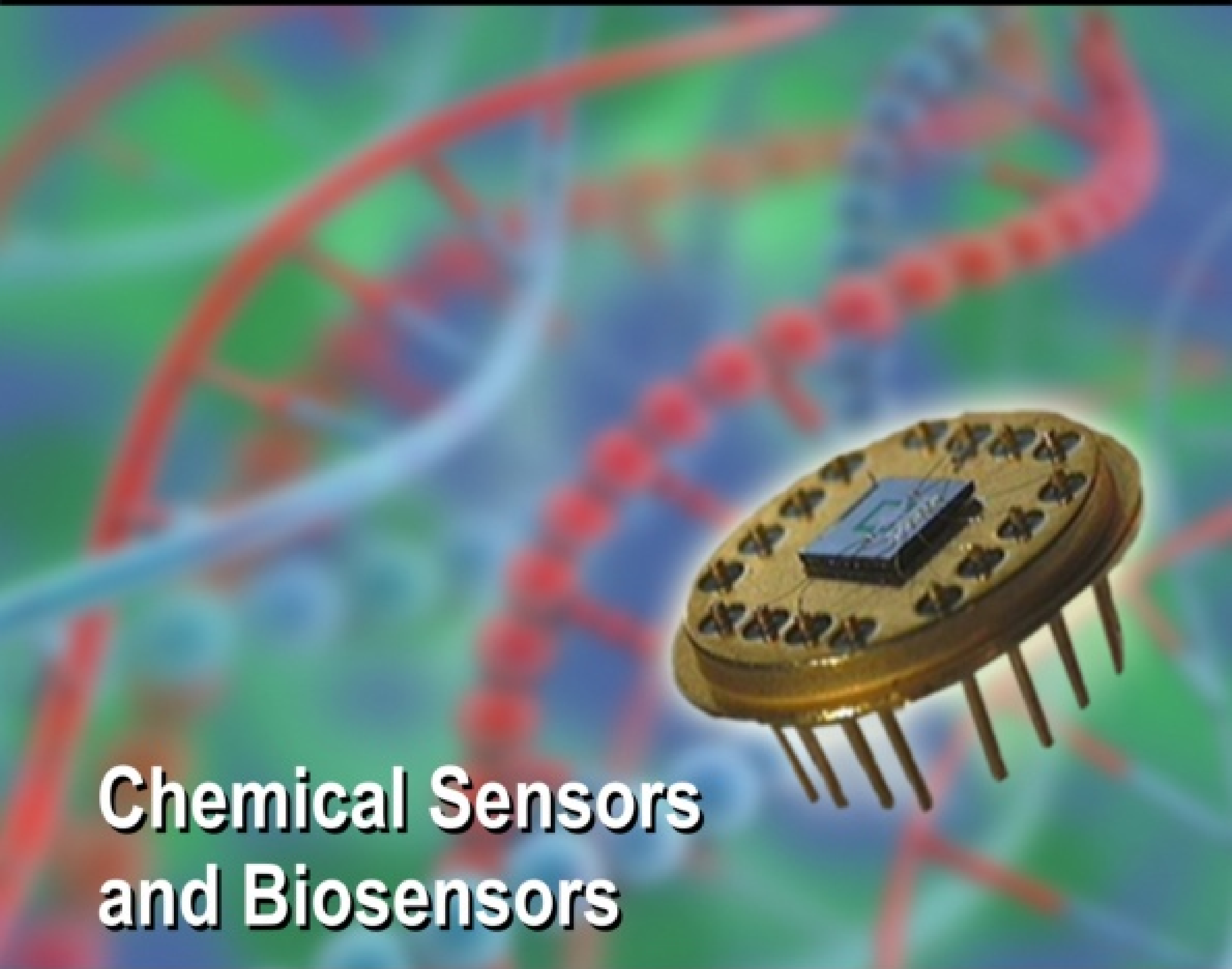

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Solid-State Conductivity of Sucrose and its Applications as Humidity and Temperature Sensors

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Abstract: Present paper reports the applications of sucrose as humidity and temperature sensors. Pellets of sucrose and sucrose mixed with 10% and 25% zinc have been made under pressure 400 Kg/cm^2 and were exposed to humidity in a specially designed humidity chamber successively. It was found that variation in electrical conductivity of pure sucrose pellet is almost linear for 5-95 %RH. When 10% zinc was mixed with sucrose, the sensitivity increases, however, linear part of conductivity Vs %RH plot contracts, which reveals that now measurable range of humidity is small for 5-85 %RH. With 25% zinc the linear part is minimum for 5-70 %RH and sensitivity is the highest among these three pellets. In case of temperature sensor, the sucrose with 10% zinc shows better sensitivity in low range of temperature, i.e. from 30 to 65°C than pure sucrose and with 25% zinc, conducting nature of zinc dominates and its temperature sensing property becomes insignificant. It is observed that at room temperature conductivity changes linearly with deliberate added amount of impurity (zinc) suggesting that conductivity may be considered as a parameter for sugar quality. Characteristic activation energies have been evaluated to establish mechanism of conduction. *Copyright © 2008 IFSA.*

Keywords: Conductivity, Sucrose, Humidity, Temperature, Sensors

1. Introduction

Humidity is another important environmental parameter after temperature, which needs to be monitored in case of storage, preservation, transportation, agriculture, food, medical and other industrial production processes. Sensing of humidity is very essential as it affects directly the end product quality. Many reports are available in which optical properties of thin or thick film have been used as sensing parameter of relative humidity [1-8] while in some cases electrical parameters like resistance, capacitance or conductivity have been used to determine relative humidity [9-17]. The most commonly used devices for measuring humidity involve infrared hygrometer and resistive type sensor. In spite of electronic type, a variety of materials such as organic polymers [18], ceramics [19] and hybrid polymers/inorganic system [20] have also been used as humidity sensors by detecting changes in capacitance or resistance. In terms of their optical sensing property polymer cladding or inorganic oxides as sensing layers have been applied and presented lately in waveguide [21], fiber optic [22] and Fabry Perot interferometric type [23] devices. The physical and chemical adsorption of water molecules in ceramic sensors is strongly related to the surface properties and hence it influences RH sensing. Material sensitivity is dependent on surface morphology, pore size and its distribution, which further affects the stability, response time and operational range [24]. Polymer sensors have mostly been investigated as bulk material with respect to changes in dielectric constant or in specific volume and mass upon interaction with water in applications involving surface acoustic wave devices and resistive type or capacitive type sensors. Polymer sensors may usually provide good mechanical properties, ease of processing and sensitivity but suffer from slow response, low accuracy at high humidity and limited long-term stability. The RH detection mechanism of polymers has also been based on fluorescence intensity [25], colourimetric absorbance [26], material density in surface acoustic wave devices [27] and refractive index [28] attenuation thus establishing optical detection means.

Extensive work has been done on X-ray diffraction study of sucrose however investigation of electrophysical properties of sucrose is very limited. Solid phase conductance of sucrose has been studied by K. Singh *et al* and their study reveals that sucrose shows semiconducting behaviour. In present work, however solid-state electrical conductivity of sucrose (GR) has been tested with respect to %RH and temperature. Hence it is seen that pellets of sucrose show humidity sensing property for entire range of %RH and temperature sensing property for low range of temperature.

2. Principle of Operation

Basic principles involved in the humidity sensing are adsorption and desorption of water vapour, which affects the physical properties of sensing element. It should be noted that adsorption phenomenon differs with absorption in which diffusion takes place. Adsorption is the process in which gas molecules or rarely liquid molecules accumulate on the surface of any material to affect physical property of that material. This is why a porous material shows good sensitivity. Greater is the change in physical property of sensing element under consideration; greater will be the sensitivity of sensor. Here, we have used conductivity of sucrose pellet as monitoring parameter and therefore sensitivity (S) of humidity sensor may be defined as the rate of change of conductivity ($\Delta\sigma$) of sensing element per unit change in relative humidity (Δ%RH).

$$S_H = \Delta\sigma / \Delta\%RH \qquad \Omega^{-1}cm^{-1}/\%RH$$

Similar analysis can be applied in case of temperature sensor and its sensitivity may be defined as

$$S_T = \Delta\sigma / \Delta T \qquad \Omega^{-1}cm^{-1}/ {}^{o}C$$

3. Experimental Details

The material used as sensing element was sucrose GR (Merck, purity 99.93%). Pellets of pure sucrose and sucrose mixed with 10% and 25% zinc powder by weight have been made by using hydraulic pressing machine (KBR PRESS, Germany) at the load of 400 Kg/cm^2. The dimension of pellets was 9 mm in diameter and 6 mm in thickness. Identical pellets have been made in pair, one for humidity application and other for temperature sensor application. For humidity sensor pellet has been exposed in specially designed humidity chamber [29] with controlled variation of relative humidity from 5-95% and corresponding variations in resistances have been observed with Sinometer (VC 9808). Conductivity has been calculated corresponding to each reading of resistance. The %RH was measured by standard hygrometer (Huger, Germany). For temperature measurement a laboratory thermometer was used and temperature changes were kept slow (1°C per minute) so that pellet could be heated almost uniformly. For both type of above applications resistance has been measured employing Cu/Pellet/Cu electrode configuration.

4. Results and Discussion

4.1. Sucrose as Humidity Sensor

Fig. 1 illustrates change in conductivity of pellets with respect to %RH at room temperature. Conductivity curve 'a' for pure sucrose is linear for maximum range of humidity i.e. from 5-95 %RH. Curve 'b' for pellet (sucrose with 10% zinc) has greater slope, this means greater sensitivity but linear part contracts and now it is limited to almost 85% RH. Similarly for higher percentage of zinc (curve 'c') the sensitivity is the greatest among these three results but linear part of curve is the smallest i.e. up to 70% RH. Thus we have seen that although pure sucrose has very small conductivity and small sensitivity but for entire range of humidity, it is better to apply. If one need a sensing

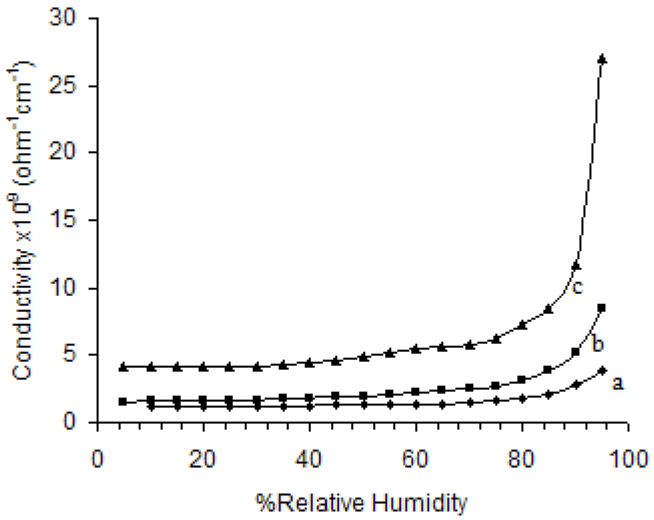

Fig. 1. Variation of conductivity with %RH.

material for smaller selective range of RH, it should be better to use sucrose mixed with 25% zinc. Fig. 2 is very helpful to clarify the aforesaid explanation. It shows that sensitivity is small but linearity is good for different pellets in specified range of RH. Fig. 3 implies that overall average sensitivity for these three different pellets increases with increase of percentage of zinc.

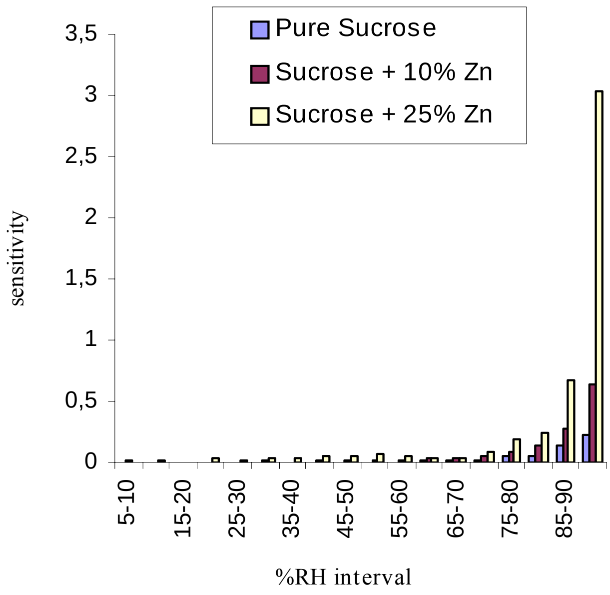

Fig. 2. Sensitivity Vs %RH interval.

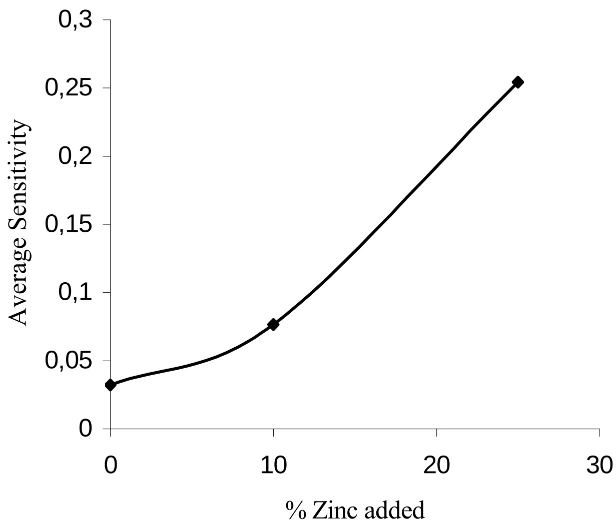

Fig. 3. Variation of average sensitivity with %zinc added.

4.2. Sucrose as Temperature Sensor

Fig. 4 shows the variation of conductivity with the increasing temperature for pure sucrose (curve 'a'), sucrose added with 10% (curve 'b') and 25% zinc (curve 'c'). The conductivity of pellet increases and for 25% zinc mixed, sucrose pellet shows almost conducting nature. We observed that variations with temperature are very small, that is why it did not behave like good temperature found that as temperature increases, conductivity increases in general. It can be understood and is acceptable because sucrose is a bad insulator or we can say it as of semiconducting nature while zinc is a conductor and when it is mixed with sucrose more and more sensing element becomes more sensitive.

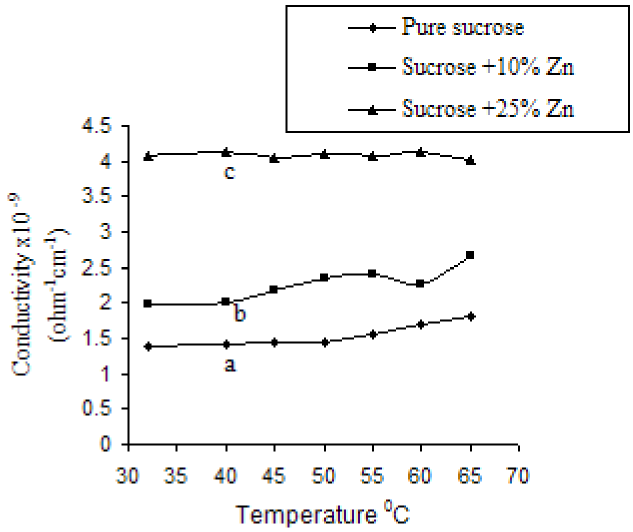

Fig. 4. Variation of conductivity with temperature.

Fig. 5 shows the nature of conductivity curve with respect to zinc content mixed at room temperature.

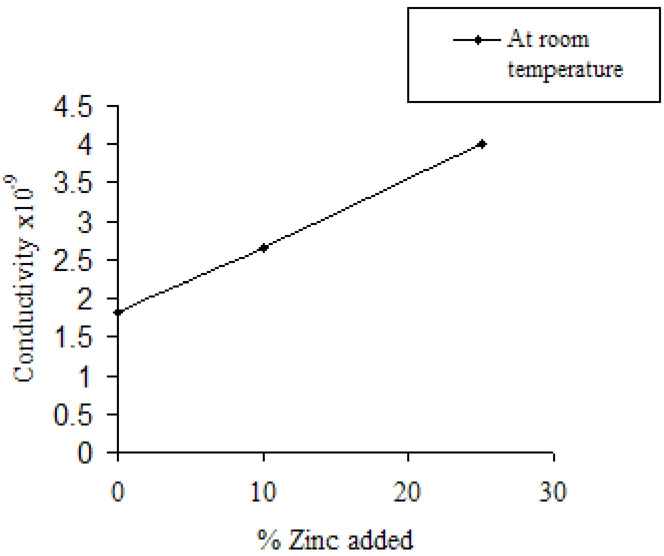

Fig. 5. Variation of conductivity with % zinc added.

Pure sucrose pellet has less conductivity at room temperature and it increases with temperature, which confirms its semiconducting nature. Similar tendency is shown by pellet having 10% zinc with increased conductivity at each temperature. In the case of pellet having sucrose with 25% zinc, the conducting nature dominates and there is no significant change in conductivity at low temperatures while above the temperature 60°C it tend to decrease. This may be strong evidence in support of dominant conducting nature. The Arhenius plot of Fig. 6 for different pellets gives activation energy for pure sucrose and sucrose mixed with 10% zinc, 0.14 eV and 0.16 eV respectively, which shows that there is protonic conduction in sucrose and may be attributed to protons of hydrogen bond (HB) –C—O—H---/---O< $^{H}_{H}$ network present in sucrose crystal.

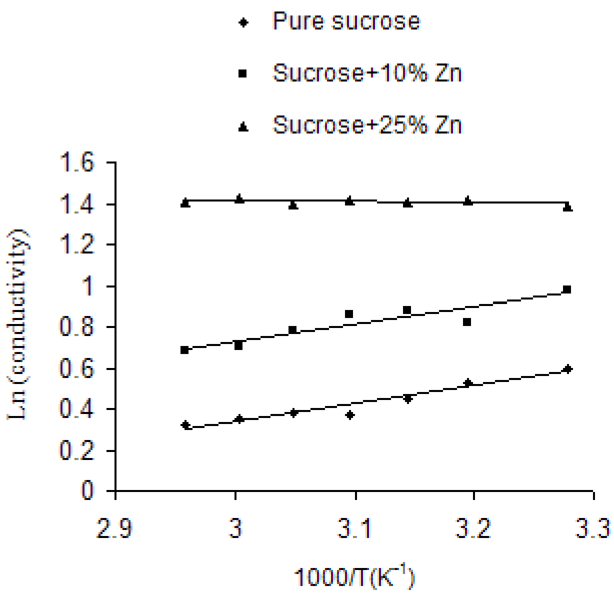

Fig. 6. Arhenius plot.

There are several considerations, which strongly favour proton of hydrogen bond network as charge carriers. The fact that when hydrogen bonded protons can take part in charge transport within ice, proteins, and resins [30], then there is no reason why this system should not be involved in transporting charge in the sucrose crystal which is also a good candidate of hydrogen bonding or where the existence of HB are well understood. A very interesting elucidation can be had from the neutron diffraction structure [31] of sucrose, which revealed two strong intramolecular hydrogen bonds (O-2^g…HO-1^f, O-5^g …HO…6^f), which serve to hold the molecule in a well-ordered, rigid conformation in which two rings are approximately at right angles. Apart from HO-4, all the –OH groups are intermolecularly hydrogen bonded. A comparative study with the conductivity of octa-methyl sucrose [32] where there is no hydrogen bonds has revealed that octa-methyl sucrose crystals have no electrical conductivity, which confirms the participation of hydrogen bonds as charge carrier, which is thought to be responsible for the observed conductivity in sucrose crystal. A comparative study with the sugar alcohols [33], which have infinite chains of –O-H…O-H…O-H- bonds, as an ice would provide an additional evidence of hydrogen bond network as charge carrier in $C_{12}H_{22}O_{11}$. However, this is beyond the scope of present investigation.

5. Conclusion

The observed conductivity with respect to relative humidity shows that sucrose may be used as sensing material in humidity sensor. The conductivity and hence sensitivity in humidity sensor increases with increase of zinc percentage but it restricts the range of %RH to be measured. Thus sucrose pellets may be used for selective range of humidity measurements. In case of temperature sensor low temperature measurement may be done with sucrose pellets. One of the most important conclusions is that conductivity measurement may suggest the purity of sugar because less pure sucrose shows higher conductivity at room temperature with linear change. Thus sucrose may be used as sensing element in humidity and temperature sensors.

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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Theory, principles, effects, design, standardization and modeling;
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- Virtual instruments;
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- Microsystems;
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