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Soil temperature Sensors in Agriculture and the role of Nanomaterials in Temperature Sensors Preparation

Almaw Ayele Aniley[1*], Naveen Kumar S.K. and Akshaya Kumar A[1]

Department of Electronics
Mangalore University, Konaje – 574199, India

Abstract

In this paper a review of soil temperature sensors and in general temperature sensors preparation from nanomaterials is presented. Introduction to soil, the role of nanotechnology in agriculture, the definition of soil temperature, the need for soil temperature detection and methods of its detection is discussed. The works of some researchers to detect the temperature and challenges of soil temperature measurement are also discussed. Finally, conclusion, personal recommendations and future outlooks will be given based on the existing works.

KeyWords: Soil, Soil Temperature, Temperature Sensor, Nanotechnology, Agriculture, Nanoceramic Powder

1. INTRODUCTION

1.1. Soil Definition

There are several definitions of soil depending on the discipline providing the definition: (Nrcs 2006)Some of them are: geologic definition, traditional definition, component definition and soil taxonomy definition. Depth of soil profile which is important for plant growth is 100-200cm(Anon 2016). Maximum length of most crops is 100cm. Some crops root length may reach 120cm.(Nrcs 2006)

[*]Corresponding author Email:-lingerayele@gmail.com

[1] Mangalore University, Konaje – 574199, India

1.2. Soil Parameters to Be Detected

Any component of soil that affect plant growth and development shall be tested or detected.

Some of them are nutrients, moisture, pollutants, ph, thermal conductivity, temperature, electrical conductivity, color, texture, structure and bulk density

1.3. The Role of Nanotechnology in Agriculture

Agriculture is the utilization of biological processes on farms to produce food and other products useful and necessary to man. Both a "way of life" and a "means of life" for the people involved in this industry(Anjou & Gertrudis n.d.). It can also be defined as the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products.

Agriculture provides food for humans, directly and indirectly. Given the increasing world population, it is necessary to use the modern technologies such as bio and nanotechnologies in agricultural sciences.

Salamanca-Buentello identified and grouped the top 10 application areas of nanotechnology in developing countries. Based on their grouping one area was agriculture enhancement in developing country. They concluded that to minimize and eradicate extreme poverty in developing countries, agriculture production should be supported by nanotechnology. As a result of this they put agricultural enhancement using nanotechnology in the second rank(Joseph & Morrison 2006).

Nanotechnology has many applications in all stages of production, processing, storing, packaging and transport of agricultural products(FAO 2013; Fao/Who 2013; Pedro 2010; Anon 2010). Nanotechnology will revolutionize agriculture and food industry by novation new techniques such as: precision farming techniques and controlled environment agriculture techniques, enhancing the ability of plants to absorb nutrients, more efficient and targeted use of inputs, disease detection and control diseases, withstand environmental pressures and effective systems for processing, storage and packaging. Efficiency of medicine increases by use of nanoparticle in animal sciences. Silver and iron nanoparticle are used in the treatment and disinfection of livestock and poultry. Levels of environment pollution can be evaluated quickly by nanosmart dust and gas sensors. Soil parameters like moisture, temperature, PH and nutrients will also be detected using nanomaterial based sensors and then possible corrections may be taken place.

2. SOIL TEMPERATURE SENSORS

2.1. Soil Temperature

World metrological organization(WMO) defines temperature as a physical quantity characterizing the mean random motion of molecules in a physical body(Iaea 2008). Temperature can also defined as a measure of how warm or cold an object is. It is related to the random thermal motion of the molecules in a substance. It is a measure of average translational kinetic energy of molecules in a material(Fahrenheit & Kelvin n.d.). The biggest changing range of soil temperature is 0 ~ 40 °C(Liu et al. 2011). The optimum average range of soil temperature for plant growth is between 20 and 30°C(K.SHUKLA n.d.).

2.2. The Need for Soil Temperature Measurement

Temperature affects several processes in soil and soil ecosystem. As a result of this soil temperature measurement is required(Valente et al. 2006). Soil temperature affects: photosynthesis, respiration, transpiration, water potential of the soil, soil translocation and microbial activity.

2.3. Factors That Influence Soil Temperature

These can be classified as surface soil temperature factors and subsurface soil temperature factors.

Surface soil temperature factors include: radiation from the sun, slop of the land, water content, vegetative cover and albedo (light reflected by the earth).

Subsurface soil temperature factors include: heat flux from the surface, water content, bulk density and heat capacity of the soil(Anon 2001).

2.4. Soil Temperature And Heat Flow

There are three major heat transfer processes in soils namely conduction, convection and radiation. These processes are affected by the soil medium(Hillel 1998).

2.5. Reviewed Papers About Temperature Sensors

Here the temperature sensors which are mostly prepared from advanced materials is going to be discussed. In the case of soil temperature sensor, there is no much work. For example a bent-stem soil thermometer is used to measure soil temperature between the ground surface and a depth of 20 cm underground, and has a bend between the bulb and the scale(WMO 2010).But this thermometer has many problems. Some of the problems of this thermometer is: it is exposed to external factors like sunlight, cold etc.., it requires removal of it from the installed place during harsh season.

The following figure shows the different types of temperature sensors(Kedzierski 1993)(So 1975; Kirkham 2014; Raytek 2003; Radiation & Pyrometer n.d.).

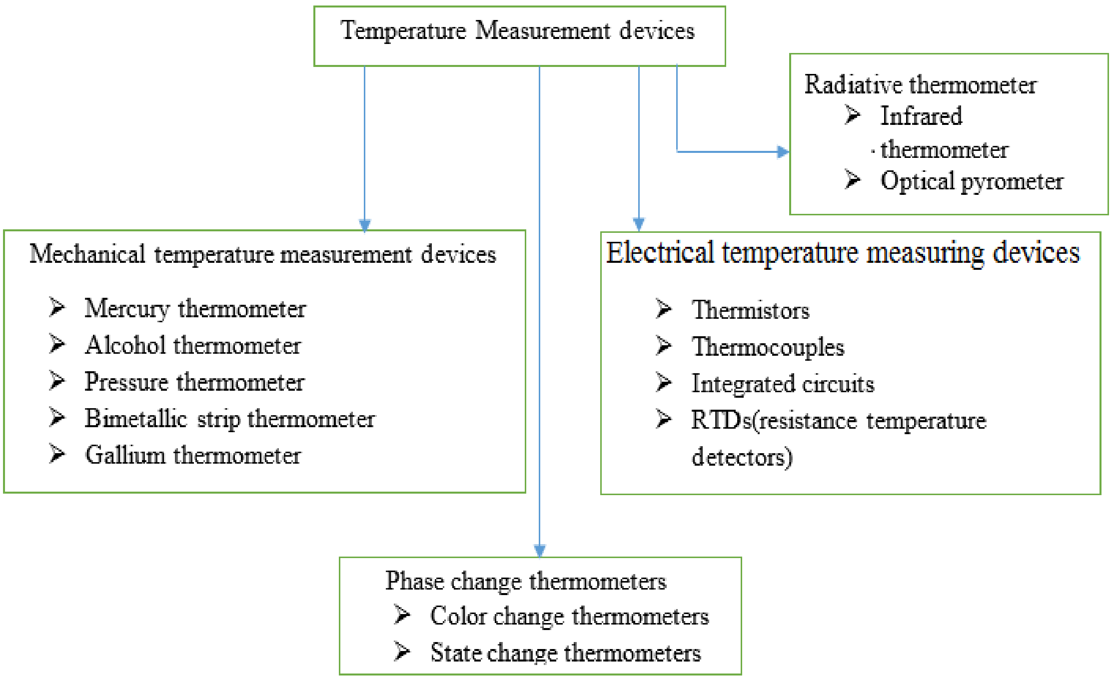

Figure 1: classification of temperature sensors

Except for IC sensors, all the temperature sensors have nonlinear transfer functions, i.e. the temperature dependence of the physical parameter under scrutiny (e.g. resistance, voltage output, etc.) is nonlinear(Feteira 2009).

Thermocouples can be prepared from one N-type and one P type semiconductor materials like semiconductor metal oxides in a certain substrate as a thin film (Gregory et al. 2010). The resulted thermocouple is nanomaterial based thermocouple with enhanced performance.

Many number of people have been trying to prepare temperature sensors from advanced materials especially from ceramic materials but they did not apply for soil temperature sensing application. The following section consists of the discussion over this concept.

Virtually all metals can be employed as RTD temperature sensors but platinum is used almost exclusively because of its predictable response, long-term stability, and durability(Fallis 2013b).

The word thermistor is derived from the two words thermal and resistor as THERMally sensitive resISTOR (Fallis 2013a). Thermistors can be classified as positive temperature coefficient resistance (PTCR) thermistors and negative temperature coefficient resistance (NTCR) thermistors. The first evidence for the NTCR behavior was registered on February 21, 1833 by the English natural philosopher Michael Faraday, who observed the resistance of silver sulfide, Ag_2S, to decrease with increasing temperature (Fallis 2013b).The principal advantages of using thermistors in measuring temperatures in the earth are: having a large change of resistance with temperature i.e.,10 times that of metals; availability in a wide range of resistances; no need of reference junction ; little affected by the usual chemical and physical conditions of the environment; small; mechanically rugged(By EUGENE C. ROBERTSON, RUDOLPH RASPET, JOEL H. SWARTZ n.d.).

(Mallik et al. 2015)prepared nano $CaTiO_3$ powder by sol-gel technique. The precursors were CaO, Titanium-iso-propoxide, concentrated HNO_3, distilled water and ethanol. The TEM analysis of the result confirmed that about 13nm size $CaTiO_3$ particles and some agglomerated particles of 20-30nm. This powder is then used as ceramic temperature sensor.

Thermistors can also be classified as low temperature (-50-150℃) and high temperature (150-900℃) thermistors. Low temperature thermistors can be synthesized from mixed oxides of Mn, Ni and Co. For example $NiMn_2O_4$ ceramic thermistor is one type of low temperature sensor(Anon n.d.).

The raw material for thermistor bodies is prepared by calcining at 800°C of the chemically pure carbonates of nickel, manganese, and cobalt(By EUGENE C. ROBERTSON, RUDOLPH RASPET, JOEL H. SWARTZ n.d.). The mixed calcined powder is compacted under high pressure into a pellet of disk or ball shape, and the pellet is then fired at 1,300℃ for 10 hours. Before sintering, when the pellet is in the green state, it has a density of about 3.0 g per cm^3 and a porosity of about 20 percent; after sintering it has a density of 4.95 ±0.05 g per cm^3 and a porosity of about 3.0 percent. The grain size of the finished thermistor is 0.1 to 10 microns.

Three types of thermistors are commercially available(By EUGENE C. ROBERTSON, RUDOLPH RASPET, JOEL H. SWARTZ n.d.): beads, disks, and rods. In bead thermistors, two separated platinum wire leads are fabricated directly through the bead by sintering the calcined oxides around them; bead thermistors are usually finished by coating with glass. Electrical connections are made to the flat ends of the disk and rod thermistors by first painting them with a silver- and-glass paste and firing at 800°C for 1 hour. A spot of low-melting silver-alloy solder is alloyed to the paste, and then tin-coated copper wire leads are inserted into the molten solder.

K. Park fabricated Graphene doped $BaTiO_3$ PTC and the resulting PTC sensor had larger grain size than the undoped once(Park 2004).

Nano-$BaTiO_3$ powder was synthesized from $TiCl_4$ and $Ba(OH)_2$ by different liquid-state (atmospheric, hydrothermal and microwave) methods(Jing et al. 2008). X-ray diffraction (XRD) pattern of the series of the nanometer powders demonstrates that $BaTiO_3$ has cubic structure. TEM shows that the products have a shape of uniform, substantially spherical particles. Powder synthesized by microwave method has the least grain size, the lowest sintering temperature, and the best dielectric capacity. Microwave method requires less reaction time, little grain size, and narrow grain size distribution.

The monodispersed $BaTiO_3$ nanocrystals have been synthesized by one-step solvothermal method. The average particle size of $BaTiO_3$ powders is as small as 5 nm with a narrow size distribution. The (Diethylene glycol) DEG was used to control the hydrolysis process of $Ti(OC_4H_9)_4$, which produced the nanoscale particles with a narrow size distribution(Zhang et al. 2011).

(Choi et al. 2016)made a significant improvements in the characteristics of positive temperature coefficient of resistance for BaTiO3/Ag-based temperature sensors. This was achieved by utilizing buffer electrode films of Al and Ni-Cu. The Ni-Cu buffer layer was more effective in reducing room temperature electrical resistance than the Al layer, which results in a significant increase in the resistance jump ratio. As a promising example, the use of a 541 nm thick Ni-Cu buffer film demonstrated a substantially increased log(Rmax/Rmin) value of 3.15, compared to 1.80 for only the Ag electrode without the buffer layer. Origin of the enhancement by Ni-Cu was attributed due to the improved ohmic behavior with a lowered Schottky barrier potential at the ceramic electrode interfaces.

Jungho Ryu fabricated NTC thermistor thick films of $NiMn_2O_4$ were deposited on glass substrate by Aerosol Deposition (AD) at Room Temperature (RT)(Ryu et al. 2009). Dense, nanocrystalline, $NiMn_2O_4$ films of ~5 μm thickness were effectively formed by AD and exhibited improved NTC characteristics like high value of B. After annealing, however, the B constant (activation energy), and room temperature (RT) resistivity were decreased with increasing temperature. Some of the advantages of this thermistor are, RT deposition, superior NTC characteristics, high deposition rate, stability of electrical property with aging, and tunability of RT resistivity.

NTCs are used in the temperature range of -50°C to 150°C, and up to 300°C for some glass-encapsulated units (Jagtap, Rane, Gosavi, et al. 2010a). For most applications, R25 values are between 100 Ω and 100k Ω. Other R25 values as low as 10 Ω and as high as 40MΩ can be produced. Thermistors are well suited for sensing temperature at remote locations via long, two-wire cable because the resistance of the long wires is insignificant compared to the relatively high resistance of the thermistor (Jagtap, Rane, Gosavi, et al. 2010a).

Shweta Jagtap et al (2009) prepared negative temperature coefficient (NTC) fine powder material using commercially available tetra hydrated acetates of Mn, Co, Ni and oxalic acid. Lead free thick film thermistor pastes were formulated using the synthesized spinel powders. Planar thick film thermistor patterns of the formulated pastes were screen printed on alumina substrates. The prepared thick film NTC thermistors showed room temperature resistance in the range of 12–29 MΩ and thermistor constant of β25/300 ranged from 4014 to 4223 K.

Bao YANG et al prepared TiO_2-substituted $Cu_{0.988}Y_{0.008}O$ (TYCO) ceramic thermistor through wet-chemical synthesis method and sintered at 970°C–990°C (Anon 2011). The TYCO ceramics exhibit typical NTC effect over a wide temperature range (25°C–300°C). The room temperature resistivity and thermal- sensitive constant of the TYCO ceramics can be adjusted by changing the content of TiO_2. The electrical behavior of TYCO thermistors resulted from both of the grain effect and grain boundary effect. Long-range mobility of charge carrier (i.e. band conduction) and hopping conduction such as Cu^{2+}+ Cu^{+} ↔ Cu^{+} + Cu^{2+} are proposed for the conduction mechanisms in the TYCO thermistors.

Generally, there are three basic types of thermistor parameters, namely:

1. ρ25=>specific resistivity at room temperature(25°C)
2. β=>the thermistor or material constant
3. The aging value that describes the stability of NTC thermistor over time.

These parameters are influenced by the composition and manufacturing process of the thermistor.

Thermistor has several potential advantages over several others like: higher temperature capability; does not require special extension lead wires and conductors or cold-junction compensation; high sensitivity; simple construction and low cost.

One of the main objective of thermistor related researchers is to fabricate lead free or low quantity of lead thermistor(Jagtap, Rane, Aiyer, et al. 2010)(Jagtap, Rane, Gosavi, et al. 2010b)(Yuan et al. 2011). Because lead is a poisonous chemical to human beings and the environmental in general.

Electrical properties of NTC thermistors are strongly dependent of the sintering condition, porosity, doping amount and structural defects(Anon 2011).

Any sensor, no matter how small, will disturb the measurement site and thus cause some error in temperature measurement(Fallis 2013b). This applies to any method of sensing: conductive, convective, and radiative. Thus, it is an engineering task to minimize the error by an appropriate sensor design and a correct measurement technique of which the coupling between the sensor and object is most critical. Sudden changes in switch contact resistance can occur as switches age. They may be variable and can go undetected unless regular system calibration checks are performed.

2.6. Challenges Of Soil Temperature Measurement

Some of the challenges of soil temperature measurement are: non-uniform temperature distribution, low resolution, low accuracy in modeling, self-heating effect and short life span of the sensors.

3. CONCLUSIONS AND RECOMMENDATIONS

Soil is the most important resource on the earth's crust. Sometimes it is known as the life of every living creature on earth. Soil will support living things and non-living things comfortably if it becomes optimum. Optimum soil contains its components in suitable composition both in quality and quantity for living things and non-living things that contains within it. One of the most important soil components that affect living things especially crops on earth is soil temperature.

Soil temperature greatly influences the agricultural productivity of one country. Soil temperature measurement has many advantages in agriculture. For example, based on soil temperature data farmers or agricultural sector investors can decide the type of crop appropriate for a certain soil, the exact time of planting the crops etc.. On the other hand these people can optimize the temperature of that agricultural field by some means or mechanism. Generally there is no much work has been done to measure the soil temperature using advanced technologies and materials like nanomaterials. Since agriculture is the backbone of one country's development especially for developing and under developed countries in the world, some technological related works should be done in this sector using advanced materials. Some of the challenges of the exiting soil temperature sensors are low resolution, low accuracy, short life span, self-heating effect, non-uniform temperature distribution.

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