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Vacuum packaging and semipassive chips for wireless temperature monitoring in industrial applications

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Abstract—**This paper describes a smart system to monitor high temperature in industrial applications. The solution includes a semipassive microchip which allows logging data and wireless reading. Protection for the electronics against high temperature environment is provided by a vacuum packaging. Thermal isolation at 150ºC and 800ºC ambient temperature allows the system to work properly during 14 and 2 minutes respectively.**

Keywords— vacuum packaging; semipassive chip; high temperature; wireless monitoring

I. INTRODUCTION

Public funds devoted lately to improve sensor functionality seek a principal objective: providing companies with smart systems for improving their products or processes. When a sensor, and the electronics that it requires to function, is meant to be integrated in an industrial application many difficulties arise. Usually, industrial applications are characterized by their harsh environmental conditions. This harshness is due to different causes: high temperatures, dirtiness, lack of space, rotating environment, lack of wired supply, etc. These restrictions demand for a packaging to protect the electronics either from those high temperatures, or from liquids. Also sensor integration in these harsh environments usually demands for wireless autonomous solutions, preferring low power ones.

Vacuum packaging technology has been used to protect different kind of sensors, thus guaranteeing a desirable performance. They are usually fragile sensors like accelerometers, gyroscopes, and also resonant MEMS, where the objective is to minimize energy loss and improve their signal-to-noise ratio. However, most of the research on vacuum packaging [1-3] relies on the hermetic encapsulation of the mechanical sensor at chip or wafer level, but not at "smart system level".

Regarding the wireless autonomous solutions for monitoring industrial machines or processes, the research has been focused on wireless communication and energy harvesting as a power supply [4,5]. But, to the best of our knowledge, none of these reports make use of semipassive sensing technology. This technology requires lower energy consumption and provides a cost effective solution compared to the ones based on microcontrollers and transceivers.

Passive or semipassive sensing technologies have been used in long term wireless monitoring. Radio Frequency Identification (RFID) device manufacturers and suppliers have recently broken into the market with specialized chips that incorporate sensing, computation, and data-logging capabilities for unconventional applications. When the working conditions require longer reading distance, chips operating in semipassive mode (battery assisted) are preferred to passive ones (without battery power). These two kind of wireless low power solutions have been reported in applications like temperature, humidity, or light monitoring [6,7], but in any case integrated in a harsh environment.

This paper presents a thermally isolated smart system for wireless monitoring of temperatures up to 800ºC. It is aimed at monitoring the temperature of melted metals in casting factories. This system is based on the specialized chip SL900A (AMS), which can work both in a passive or semipassive mode. Due to the high temperature of the application, the semipassive mode is preferred. So the electronics, which is thermally vacuum/air isolated, is also supplied with a coin cell battery. A thermocouple and antenna standing out from the packaging allow external interaction, providing outer environment temperature monitoring and wireless data communication.

II. DESIGN

The packaging conforms a jar-shaped storage, made of stainless steel. The jar contains a double chamber, where the electronics are placed in the inner volume, and the intermediate volume is filled by vacuum or air (Figure 1A). A ceramic disk (1) is placed in between the jar (2) and the cover (3), with the purpose of reducing the thermal conduction between the thick metallic cover and the thin jar wall. The jar fits tightly in the cover.

Figure 1B shows the electronics designed to connect a type K thermocouple to the SL900A chip. This electronics includes a button cell (4) and an LC impedance-matching network (5) to connect the RFID chip to a 50 Ω monopole-like antenna. This connection is carried out through a coaxial cable.

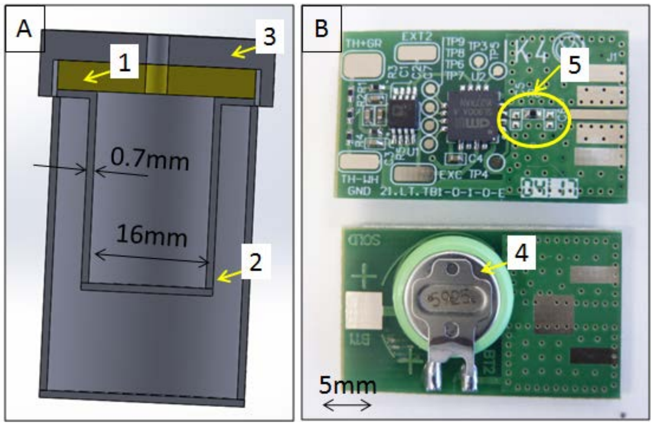

Fig. 1. A) Schematics of the packaging (section view). B) Electronics based on SL900A chip for working in semipassive mode

All the thin-walled pieces were soldered by stainless steel Tungsten Inert Gas (TIG) welding. The intermediate volume was successfully vacuum "filled" by using electron-beam welding. This technique allowed to extract the air from the intermediate volume. After achieving a 10^{-5}mbar vacuum level, a 1mm diameter hole is reflowed, sealing completely the double chamber.

The antenna connected to the electronics, stands out from the metallic packaging through an orifice that also goes through the ceramic disk (Figure2A). The ground connection of the antenna is done by TIG welding the mesh of the coaxial cable to the inner surface of the packaging cover (Figure2B).

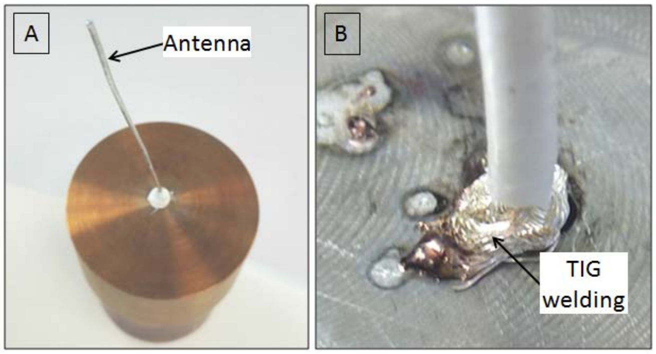

Fig. 2. A) Antenna standing out from the cover of the metallic packaging. B) Detail of the antenna ground connection on the inner side of the cover by TIG welding

A limit working temperature of 80ºC for standard electronic devices has been considered. Ansys-Fluent software has been used to calculate the time range for the electronics, inside this isolated chamber, to function as data logger, before getting hotter than 80ºC. The thermal path from the metallic thermocouple and antenna lead has been disregarded in the simulation due to their small cross sections. A transient thermal analysis calculates around 14 min as the necessary time for the inner temperature to reach the electronics working limit of 80ºC when the outside temperature is at 150ºC (Figure 3). When the outer temperature increases up to 800ºC, simulated data show that this time is reduced to around 2 min.

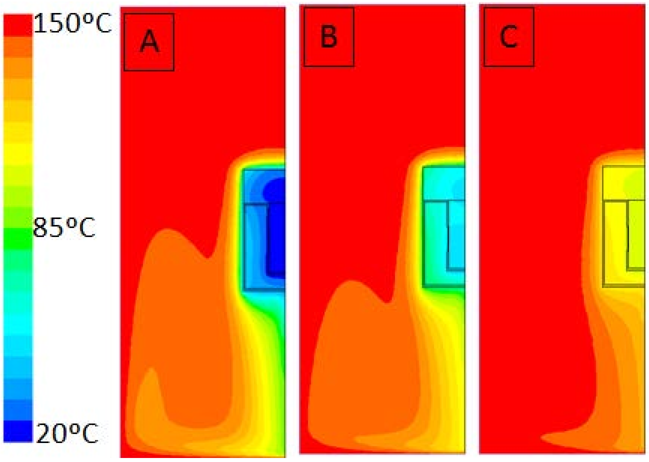

Fig. 3. Heat transferring from external environment to electronics location at different times. A) 80s. B) 300s. C) 950s

III. RESULTS AND DISCUSSION

Two different characterizations have been performed: thermal isolation and wireless data logging. For the thermal isolation, the following scenarios were analyzed. The first one was an oven with a temperature set of 150ºC. A thermocouple was glued to a copper thermal mass inside the jar (Figure 4A and 4B). The packaging was placed inside the oven when the temperature set of 150ºC was reached. Figure 4C shows the temperature recorded by the thermocouple. A 2min delay in heating is obtained when vacuum isolation is used, compared with another jar where double chamber is filled with air. This means 14min are available for temperature recording when the electronics is isolated with a vacuum packaging, while 12min are available when air is the thermal barrier.

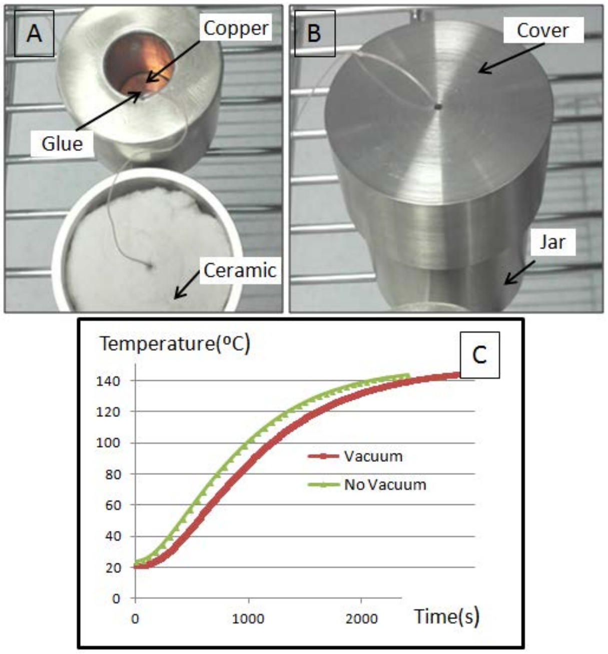

Fig. 4. A) Inside view of packaging with thermal copper mass, ceramic isolator and thermocouple glued. B) Mounted packaging with cover through hole for thermocouple/ antenna standing out. C) Temperature recorded by the thermocouple

Then a second scenario at higher temperature was analyzed. In this case the packaging was placed inside a furnace when it reached its temperature set of 800ºC. The temperature recorded by the thermocouple inside the packaging shows that the available time to take data before the electronics inside reaches 80ºC is around 2min. At this temperature range, both vacuum and air isolated packaging show similar thermal conductivity. This behavior agrees with the fact that at higher temperatures neither conduction, nor convection dominates heat transmission, but radiation. In order to reduce this heating by radiation, the inner surfaces of the double chamber should be anti-reflective. A low emissivity metal covering on those surfaces would improve this thermal isolation.

For the wireless logging verification, first the wireless transmission through the furnace metallic door was verified. As it was correct, the whole system was placed inside the furnace. A thermocouple was fixed to the electronics and stood out from the packaging. This way, the thermocouple measured directly the temperature inside the furnace. Figures 5A and 5B show the contactless reading through the monopole antenna, and the data recorded inside the furnace at 800ºC. The consumption of the SL900A in this semipassive mode at this range of temperatures during 2min is below 0.3µAh.

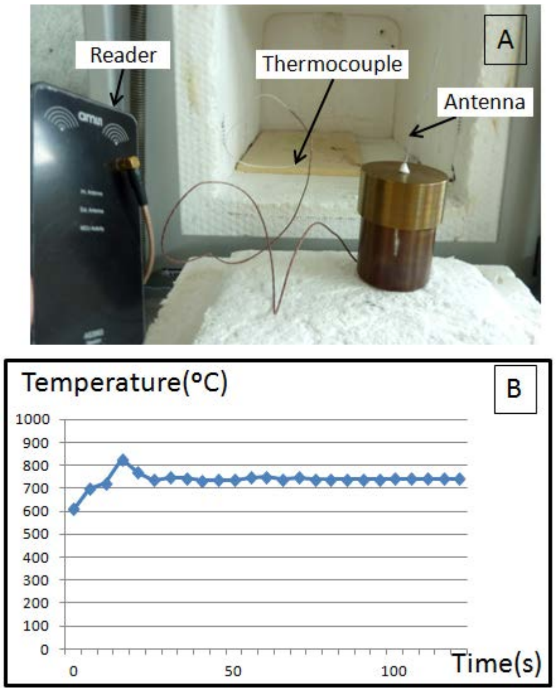

Fig. 5. A) Reading through antenna connected to electronics thermally isolated from high external temperature. B) Temperature recorded by the thermocouple inside the furnace

IV. CONCLUSIONS AND FUTURE WORK

A thermally isolated smart system for wireless monitoring of temperature in industrial applications is presented. Simulated and experimental results demonstrate data logging time ranges around 14min and 2 min at 150ºC and 800ºC respectively. The consumption of the electronics working in a semipassive mode at 800ºC, for those 2min, is below 0.3 µAh. So this system is a low power solution.

Future improvements in this packaging will include a low emissivity metallic covering of double chamber inner surfaces. Validation in a scenario like a casting ladle laboratory will prove the advantages of this low cost semipassive based solution for wireless data logging, protected against harsh temperature conditions.

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