Elevated Temperature Sensors for On-Line Critical Equipment Health Monitoring

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Introduction:

The objective of the proposed research program is to improve high temperature piezoelectric aluminum nitride (AlN) sensor technology to make it useful for instrumentation and health monitoring of current and future electrical power generation equipment. The sensor's temperature range will be extended from approximately 700°C to above 1000°C. Ultrasonic coupling to objects at very high temperatures will be investigated and tailored for use with the sensor. The sensor will be demonstrated in a laboratory simulation of an application of health monitoring for power generation equipment.

Over the past seven years, research has been conducted at the University of Dayton into the properties and behavior of oriented polycrystalline AlN films. The films have a piezoelectric constant similar to that of quartz, a common piezoelectric material. A chemical vapor deposition process is used to make useful films up to 0.1 mm thick with deposition times less than 1 hour. The deposition process was previously improved to the point where defect-free films can be reliably produced. These films, deposited on tungsten carbide substrates, are useful up to around 700°C, where oxidation of the carbide substrates becomes problematic. At slightly higher temperatures, the AlN films themselves begin to undergo significant oxidation. Additionally, the tungsten carbide substrates have an acoustic impedance 2.5 times that of AlN, causing an undesirably narrow bandwidth for ultrasonic pulses produced by transducers built from the films.

The process and equipment to create piezoelectric thick films by CVD was reactivated in a reliable fashion during the early part of the program. In addition to the tungsten carbide substrates, films have been created on titanium substrates. The titanium substrates were intended to duplicate or extend the temperature range of the tungsten carbide substrates, while providing a very good impedance match to the AlN films. While we were able to apply films to titanium, several drawbacks have been discovered which have caused us to abandon this approach. First, while the impedance match successfully resulted in the production of broadband ultrasonic pulses, these pulses were substantially weaker than those produced by the films on carbide. Second, upon heating in air, the films tended to lose adhesion to their substrates. It is believed that both the reduced strength and loss of adhesion are related to the thermal expansion mismatch between the titanium and AlN.

The results with the films on titanium have helped guide our selection of alternate substrate materials to explore for very high temperature applications. Thermal expansion is a primary consideration, with acoustic impedance given a secondary status. Silicon carbide has been selected as the next substrate material for deposition, and deposition should be underway by early summer 2003. Additional materials under consideration are ceramics with a conductive electrode or refractory metals or carbides with an oxidation-resistant coating. A final possibility for some applications might be to enclose the AlN film and substrate in a sealed housing from which oxygen is excluded.

A parallel path approach to look at an alternate deposition method, pulsed laser ablation, is underway. If this method is successful, it will provide an alternate source of thick piezoelectric AlN films. Another possibility is the use of AlN single crystal material. This material is now being produced in limited quantities, with the process being scaled-up to commercial quantities over the next few years. We plan to monitor and evaluate these alternate approaches.

An additional task under this project is to examine ultrasonic coupling at temperatures up to and exceeding 1000°C. This task will be underway in summer 2003, will begin with a literature review, and continue through the demonstration project. Candidate methods include pressure-coupling with a metal interface, or the use of molten glasses as couplants. Ultrasonic coupling is important because the useful low frequency cutoff of a piezoelectric sensor will increase with temperature as the resistivities of the sensor material and electrical insulation fall off. At very high temperatures, the sensor will likely be most useful for high-frequency signals, and for the transmission and reception of ultrasonic energy. This transmission and reception will require coupling to the structure of interest.

The final task under this program will be to demonstrate the use of the sensor in the power generation industry. While work on the sensor material progresses, we will institute communication with DoE and industrial personnel in the power generation industry to focus sensor development in an area of equipment health monitoring which will provide the best chance of high payoff and success. Laboratory testing of sensors under the conditions present in this application will then be performed to demonstrate the viability of the sensor technology. A preliminary design for an industrial sensor based on this experiment will be completed. As an example, a common use of ultrasonics is to measure the thickness of a material. Performed on-line at high temperature, such a thickness measurement could be used to monitor the extent of corrosion damage in metallic components. Similar methods can be used on nonmetallic materials such as refractory ceramics. Ultrasonic waves may additionally be used to monitor bonds, such as that between a metal and a ceramic, as found in thermal and environmental barrier coatings commonly found in power generation equipment.

No journal articles or presentations have been published or submitted resulting from the grant to date. Matthew Pacyna is an undergraduate student who has helped with the project thus far; one or two additional students will be employed on the project through the summer and fall of 2003.