MEMS PIEZO PRESSURE SENSOR FOR MILITARY APPLICATIONS

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ABSTRACT

The structural integrity and ballistic accuracy of gun-launched projectiles are related to the in-bore environment, and to date, these parameters cannot be routinely measured. The ability to measure these quantities and to compare them to design parameters during the system development would vastly improve the performance and reliability of projectiles. Insertion of smart material MEMS (Micro-machined Electro-Mechanical Systems) sensors into projectiles will provide the methodology required to develop more precise and lethal projectiles for future combat systems.

INTRODUCTION

ARL has developed smart material (Zakar, 2001) piezoelectric PZT (Lead Zirconate Titanate) pressure sensors for extremely harsh environments encountered in projectile launched munitions. The ARL in-house state-of-the-art MEMS fabrication facility and advanced technology enable miniaturized, low cost sensors that are rugged enough to withstand pressures of 100,000psi, and an axial acceleration of 75,000g. This paper describes a novel device using a micrometer (µm) size thin film sol-gel deposited PZT sensing material that produces a linear electrical signal output in response to an applied pressure. It is ruggedly designed with no moving parts, such as diaphragms, or suspended parts unlike conventional devices. Accurate in-bore pressure measurements can be fully acquired as there is no lag or recovery time associated with displacement of moving parts during the launch phase of projectiles. These sensors are compatible with commonly used tracer well geometries and components that have been utilized in demonstration telemetry flights by Weapons and Materials Research Directorate (WMRD) in connection with the Hardened Subminiature Telemetry and Sensor System (HSTSS) program. The insertion of a PZT pressure sensor into the tracer well system of direct fire tank ammunition enables routine in-bore pressure measurements without major projectile modifications. It also enables the development of smart munitions concepts where launch disturbances can be computed through knowledge of the in-bore excursion.

The selection of PZT thin film was due to several advantages over silicon. Bulk PZT has long been employed as a workhorse piezoelectric material for high performance macro-scale transducers, primarily due to its high electromechanical coupling strength.
ARL has consistently demonstrated the preparation of superior quality PZT (52/48) sol-gel thin film ~ 0.5 µm (Piekarz, 2003) for prototyping of piezoelectric sensors. The PZT is sandwiched between top and bottom Pt (platinum) electrodes with Ta (tantalum) as an adhesive material. A dielectric layer consisting of SiO_2 (silicon dioxide) and Si_3N_4 (silicon nitride) is used as an interfacial layer to improve the material coefficient of expansion mismatch on the silicon substrate. ARL developed reactive ion etching processes for patterning SiO_2 (Washington, 2004), and PZT (McLane, 2001). We studied the development of thin film residual stress in a Ta/Pt/PZT/Pt stack structure on Si/SiO_2 and Si/Si_3N_4 substrates, experimentally demonstrated that annealing temperatures have a profound effect on the PZT layer, and that film delaminating can occur if the stresses are not controlled.

RESULTS

A first generation miniature pressure sensor with active PZT capacitor dimension (100 x 100 µm) was patterned using a combination of ion beam milling and RIE, and assembled in a customized stainless steel package. Commercial off the shelf packaging for this type of application does not exist. The packaged sensor was tested to a high pressure of 40,000 psi. An improved second generation PZT structure 3 mm in diameter was designed and fabricated to withstand even higher pressure loads and produce greater electrical charge response. A micrograph of the second generation sensor after the fabrication sequence prior the final deposition of the SiO_2 passivation layer is depicted in figure 1. Finally a cross-sectional view of several inner material layers within the outer edge of this device is shown in figure 2.

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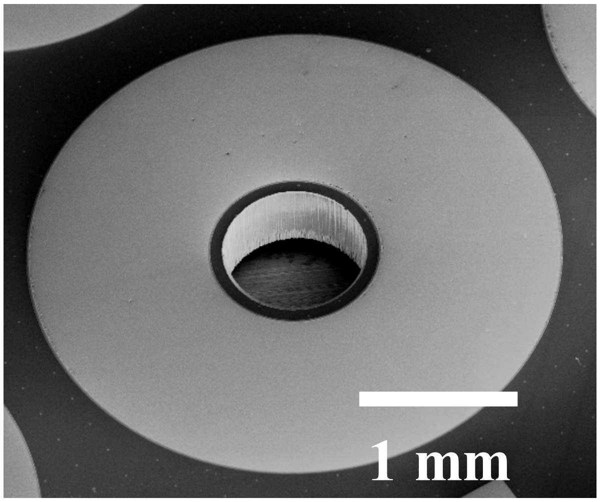

Fig. 1. Fabricated second generation PZT pressure sensor with a precision centered channel deep reactive ion etched (DRIE) through a silicon substrate needed for top electrode interconnection.

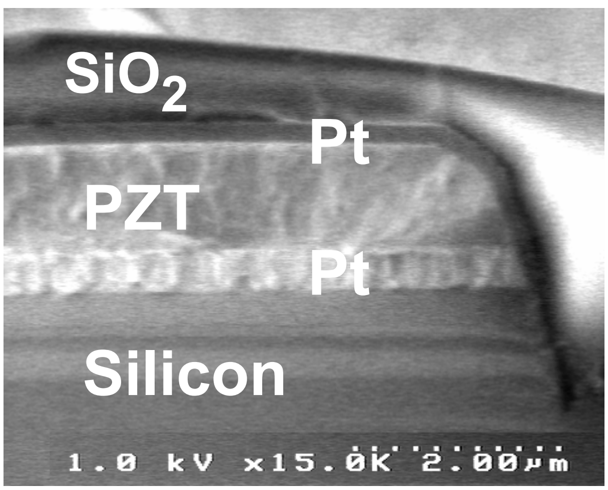

Fig. 2. Cross-sectional view of the inner layers at the edge of the device after the final process coating step of SiO_2 deposition.

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CONCLUSION

PZT is a smart material that can be used as a multi-fuction integrated film for both sensors and actuators. It is widely used in memory cells of logic circuits. In missile applications that require the use of a guidance and control systems, it can act as a backup inertial measurement unit (IMU). PZT is also gaining attention in the field of power MEMS for applications in energy storage and power reclamation. Insertion of smart material MEMS sensors into projectiles will provide the methodology required to develop more precise and lethal projectiles for future combat systems.