

## Piezoelectric Single Crystal for Improved Fuel Injector Application

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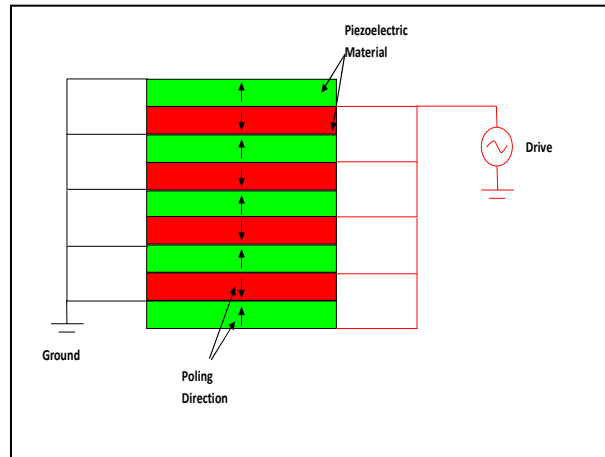
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**Command: ONR - SBIR**

**Topic: N07-076**

## PROBLEM STATEMENT

Pulse Detonation Engines (PDE) offer greater thrust and efficiency than conventional jet engines, and research in Navy and Air Force labs is ongoing. As there are no rotating parts, fuel injection requirements are different than is traditional and delivery of a precise fuel:air mixture is needed to ensure maximum effectiveness, which current injector technology cannot provide.

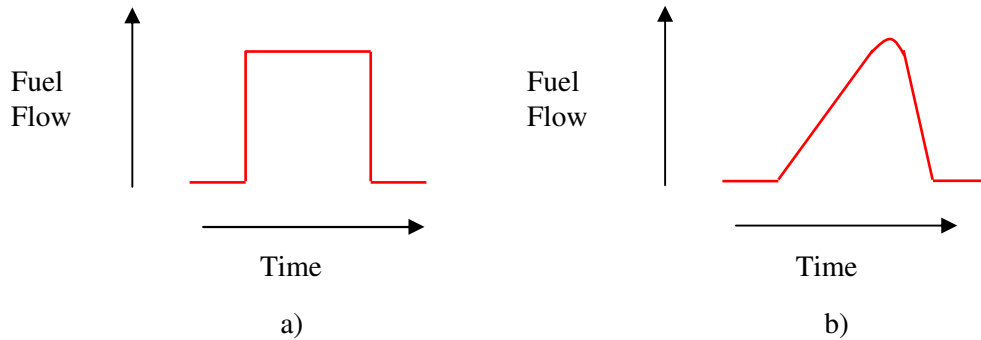
## WHO CAN BENEFIT?

In addition to the basic PDE use, this injector technology could be adapted to any petrol or diesel driven engine in Department of Defense (DoD) systems. The precise control offered would allow for a choice of improved efficiency, emissions, or power – extending operations duration and reducing fuel costs. Civilian use in automobiles is also a possibility.

## BASELINE TECHNOLOGY

Current PDEs use commercially available fuel injectors for automobiles. Although commercially available injector costs are in the 10s of dollars range, they do not meet stringent PDE performance requirements because their slow response time does not allow for control of operation to the degree needed (up to 35g/s of JP-10 fuel at 80-100Hz). Figure 1 illustrates the response time and profile of a traditional fuel injector as compared to that of the piezoelectric single crystal fuel injector. As shown in illustration Figure 1(b), it is expected that during each cycle, the PDE fuel:air mixture should be slowly ramped to a peak before rapid shutoff. Commercially available fuel injectors do not

provide the necessary fuel:air mixture injection control. The new injector stacks using single crystal piezoelectrics will allow for the type of injector rapid response operation necessary to meet the operational performance requirements of future PDE operations.



**Figure 1 – Time response of fuel flow for a) traditional and b) SBIR new fuel injectors**

**TECHNOLOGY DESCRIPTION**

The new fuel injector technology provides precise control of fuel delivery to engines and is superior to existing technology. They allow for fuel distribution to be optimized for each system, resulting in increased fuel efficiency, power, and emissions control. The baseline solution is typically solenoid actuator based, which results in on/off operation rather than smooth control. Simple piezo based injectors currently are larger and have lag time from hydraulic systems associated with them that are not needed in this new variation.

<b><u>Feature</u></b>	<b><u>Advantage</u></b>	<b><u>Benefit</u></b>
Single crystal materials instead of ceramics	Greater stroke per volt, lower hysteresis	Smaller actuators or greater stroke for same size as standard, easier control by electronics
No hydraulic amplifier section	Direct action on outlet nozzle	Reduced response lag, greater control of fuel flow, less components and simpler design.
Direct analogue control	Precise control of fuel flow	Allows for greater fuel efficiency, power generation or emissions control
Fewer components	Reduced size and complexity	Smaller, more robust, less expensive components.

Direct replacement of existing technology with new technology should be possible, reducing implementation costs. Simple additional drive electronics will be required over existing approach, however these will be small and low power.

Early versions of ordinary piezoelectric fuel injectors already have demonstrated the economical aspects of the technology, and that improvements in the performance of the actuator stack are the limiting factor in system performance. Another significant advantage of this technology is that replacing fuel injector systems on existing engines could result in these improvements, without the need for replacement of the entire engine.

Piezoelectric single crystals have improved significantly in recent years, and offer high strain capability and high coupling efficiencies significantly beyond conventional piezoceramics – for example maximum strains of around 1% in single crystal compared to ~0.1% in piezoceramics – while prices have reduced significantly. This high strain capability makes the piezoelectric single crystal an ideal candidate for actuator purposes such as are found in fuel injectors.

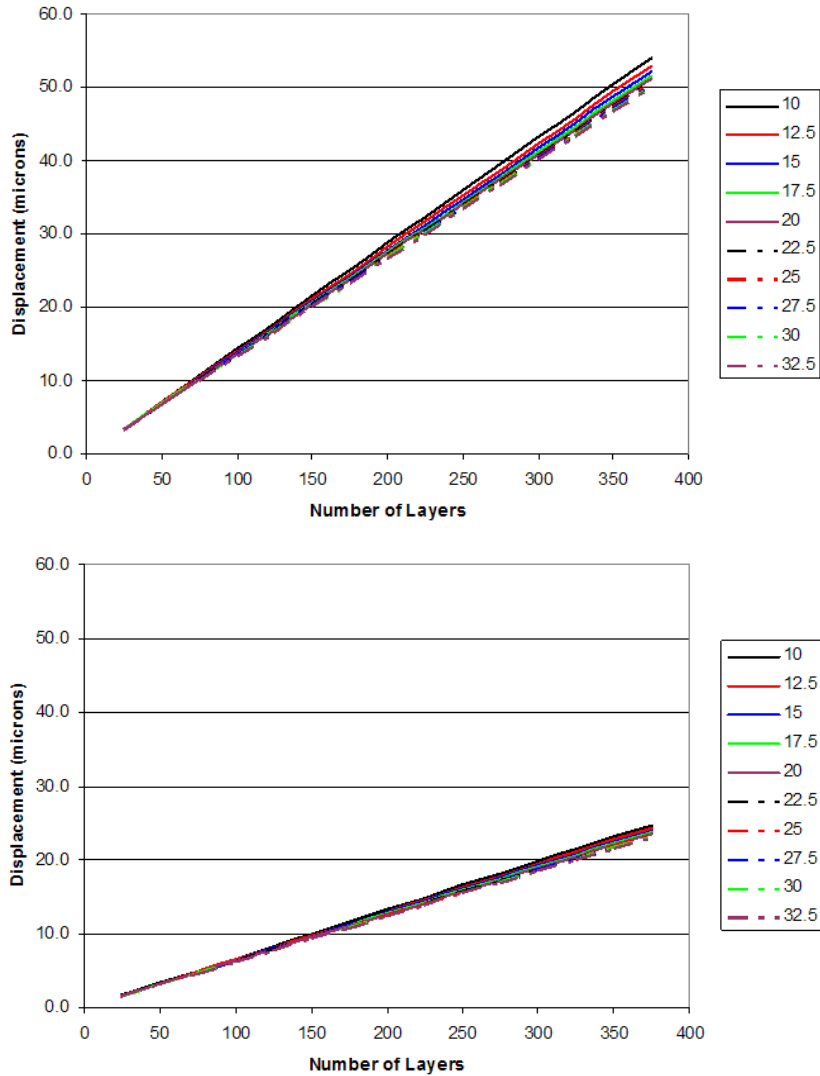
The introduction of the piezoceramic stack actuator to replace the solenoid has resulted in further improvements to performance:

- 1) Faster response than solenoids
- 2) Linear, analogue response (many positions between open and closed)
- 3) Smaller, lighter injectors
- 4) Smaller high-pressure pumps required

### **CURRENT STATE OF DEVELOPMENT**

Phase I demonstrated the viability of the approach. Current development in Phase II has seen the design of the prototype complete, the drive stack designed and manufactured, and the injector housing in the process of manufacture. TRL level of ~4 is warranted at this time. Assembly of the various components is scheduled for October 2009 and testing to begin Oct/Nov 2009. These test will be carried out at the Naval Postgraduate School in Monterey. Future work will build on the results of those tests to improve the design, and to implement for working systems (temperature considerations etc)

Figure 2 shows the comparison of the performance of the single crystal piezoelectric based stack versus the standard piezoceramic material (Sonox). As can be seen, for a given number of layers and voltage drive, the single crystal stacks outperform the traditional stacks by a factor of 2 in displacement (stroke). This performance improvement does not account for the lower hysteresis and potential higher safe drive limits of the single crystal piezoelectric based stack.



**Figure 2 – Stack displacement against number of layers for various stack thicknesses. Top – Single Crystal, Bottom – Standard Piezoceramic**

## **REFERENCES**

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## ABOUT THE COMPANY

Weidlinger Associates Inc is the developer and provider of PZFlex ([www.pzflex.com](http://www.pzflex.com)), the premier computer simulation package for the piezoelectric and ultrasound industries. WAI has over 50 years experience of the design and prototyping of piezoelectric devices and has several staff engineers skilled in their design. Through application of skills learned in working with the medical ultrasound industry, non-destructive testing, SONAR, and other fields using piezoelectrics and actuators, WAI can bring a wide variety of expertise and knowledge of the latest materials and developments in the industry to any problem.