The Role of Advanced Sensing Technologies in Pollution Prevention

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The New Mexico State University Physical Science Laboratory has developed applications for advanced fiber Bragg grating strain sensor technology that can play a significant role in Department of Defense pollution prevention programs. One of these is the Portable Munitions Monitoring System (PMMS). The PMMS is designed to provide improved data so that inventory management can be based on the actual storage conditions and the physical state of individual munitions. Compared with current practices, this approach has the potential to reduce the need to destroy lots that are presumed to be out of specification based on limited testing. Another application under development is to use the sensors to monitor critical aircraft and vehicle components. Basing replacement decisions on the actual condition may reduce the need to dispose of old parts and to manufacture replacements.

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Introduction

Pollution prevention programs usually are based on approaches such as

- Improving manufacturing processes to reduce environmental emissions, e.g. using improved chemical reactors to increase yields of products
- Substituting environmentally benign materials for more polluting materials, e.g. using water-based rather than VOC-based coatings
- Minimizing waste, e.g. using improved processes to reduce waste
- Improving waste treatment and disposal, e.g. using improved treatment processes
- Recycling
- Redesigning products to reduce life-cycle emissions, e.g. substituting advanced materials to obtain improved service life

This paper focuses on a sensing technology that enables pollution prevention based on improvements in inventory management made possible by improved knowledge of the state of products in storage. It is particularly applicable to Department of Defense (DoD) munitions and weapons systems.

Background

Current estimates are that up to 9 percent of DoD's $22 billion ammunition stockpile is unserviceable. Principal causes of failure are exposure to severe temperature and humidity conditions in storage and transit. It is of the utmost importance that these items be reliable and safe to handle when they are required. Therefore, it is critical that unserviceable items be removed from storage. Safety and reliability concerns dictate that misidentification that results in removal of good items is more acceptable than failure to remove defective items, and current practices are biased in that direction.

Weapons systems and munitions typically are procured in production lots. Production may occur intermittently, and in extreme cases, there may be only one or a few production runs. Therefore, the items are designed to be stored for extended periods. Nevertheless, storage life is finite, and effective inventory management practices are required.

Most current inventory management practices, especially for low-value items, are based on lot testing. Representative samples of specific production lots are removed from inventory and functionally tested. Those lots that fail to meet predetermined statistical performance criteria are presumed to be defective in their entirety even if all items in the lot were not subjected to the same storage conditions. The entire defective lot is removed from inventory typically to be destroyed by open-burn or open-detonation. This results in significant environmental costs from

- Direct emission of pollutants into the atmosphere and surface water
- Possible eventual migration of pollutants into the ground water and beyond the disposal site boundaries
- Additional pollution resulting from manufacturing replacement products

An inventory management practice that reduces the need to destroy products that are presumed to be defective will reduce environmental emissions. One of the requirements to improve management is better data on storage conditions and on the actual state of the items in storage.

Fiber Bragg Grating Strain and Temperature Sensors

The New Mexico State University Physical Science Laboratory (PSL) has developed an innovative non-destructive measurement approach to facilitate monitoring munitions in storage and transit. Although the temperature and humidity in storage facilities are routinely recorded, existing approaches focus on the facility rather than on the individual items stored within it. This system could significantly reduce the fraction of the munitions stockpile that is presumed to be unserviceable. If only 10a fraction of the munitions thought to be unserviceable could be salvaged, annual cost savings would be in the hundreds of millions of dollars, and this does not consider the reduced environmental costs.

Our approach makes use of advanced fiber Bragg grating (FBG) strain and temperature sensors. These sensors have many important advantages

- No electric current is required at the sensor locations
- The sensors are immune to EMI
- Very fast readout is possible (important for dynamic monitoring during shipment)
- The sensors are small, light-weight, and have low thermal and inertial mass, so they have little potential to perturb system being measured
- They exhibit high sensitivity and low noise
- A single fiber strand can contain multiplexed sensors (> 30 has been demonstrated)
- The sensors can measure temperature and strain directly and other parameters such as shock with an auxiliary set-up
- Sensors for different measurements can be mixed or matched on a single fiber
- The technology has high potential for low cost production, miniaturization, and low power consumption

Operation of Fiber Bragg Grating Sensor Systems

Figure 1 is a schematic diagram of a basic FBG strain and/or temperature measurement system. A broadband infrared light source is coupled into a fiber containing one or more FBGs. Radiation reflected by the gratings is coupled into an analyzer. In essence, an FBG is a highly wavelength-selective reflector. The analyzer measures the wavelength of the reflected light as shown in Figure 2. When the length of the grating is changed as a result of mechanical stretching or thermal expansion, the wavelength that it reflects shifts. For a measurement of pure strain, the degree of elongation can be computed from the wavelength shift, and the strain is simply the fractional change in length. For temperature measurements, the situation is more complex because the index of refraction of the fiber also exhibits temperature dependence which must be accounted for in the calculations. If both temperature and strain changes are expected, it is best to incorporate an unstrained sensor, which reacts only to the temperature change.

Figure 3 shows how the signals from multiple sensors are multiplexed on a single fiber. To ensure that data can be successfully read from a set of multiplexed sensors, it is necessary to ensure that the respective reflected wavelengths do no shift so far as to overlap the wavelength reflected by any other sensor in the array. Figure 4 illustrates the production of FGBs by exposure of photosensitive optical fibers to intense interfering laser beams.

Application to Munitions Monitoring

Monitoring munitions involves two distinct elements: monitoring the storage conditions and monitoring the actual physical state of individual items. In general, environmental conditions within storage facilities, specifically temperature and humidity, are monitored routinely. However, information often is recorded only at a single point using rather simple methods such as thermometers that record on paper charts. The munitions monitoring system developed by PSL provides sophisticated communications capability to transmit the data to a remote location. The system supports a number of different methods of communication as may be required for a specific location. These include fiber optic connections, wired Ethernet, and telephone dial-up. This capability alone is a significant improvement over current monitoring practices.

Currently, the physical condition of munitions is not monitored routinely. PSL's FBG technology permits measurements of a number of physical characteristics. If applied during shipment, the sensors can detect and record shock and vibration. Shock and vibration, even if they do not produce evident damage, can loosen or damage electronic components, crack solid propellant grain, and cause misalignment of critical guidance components. Temperature and humidity exposure can cause swelling and cracking of propellant grain and explosive fill, delamination of composite components, and corrosion of metal components. Many of these changes can be detected with FBG strain sensors.

Conclusions

The FBG technology that we have developed and demonstrated has the potential to enable monitoring of individual munitions in storage and transit. This will allow decisions to remove items from inventory to be based on the storage conditions and physical state of the individual items rather than on lot testing. Ultimately, this will result in destruction of fewer items and thereby prevent the pollution associated with the destruction and manufacturing of replacements.

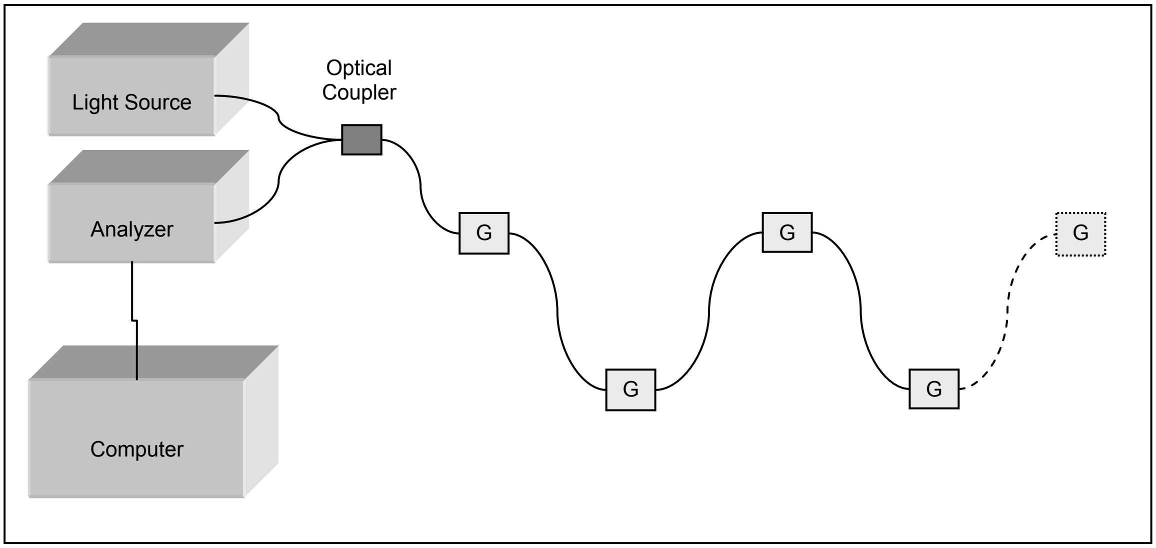

Figure 1. A schematic diagram of a fiber Bragg grating strain and/or temperature measurement system.

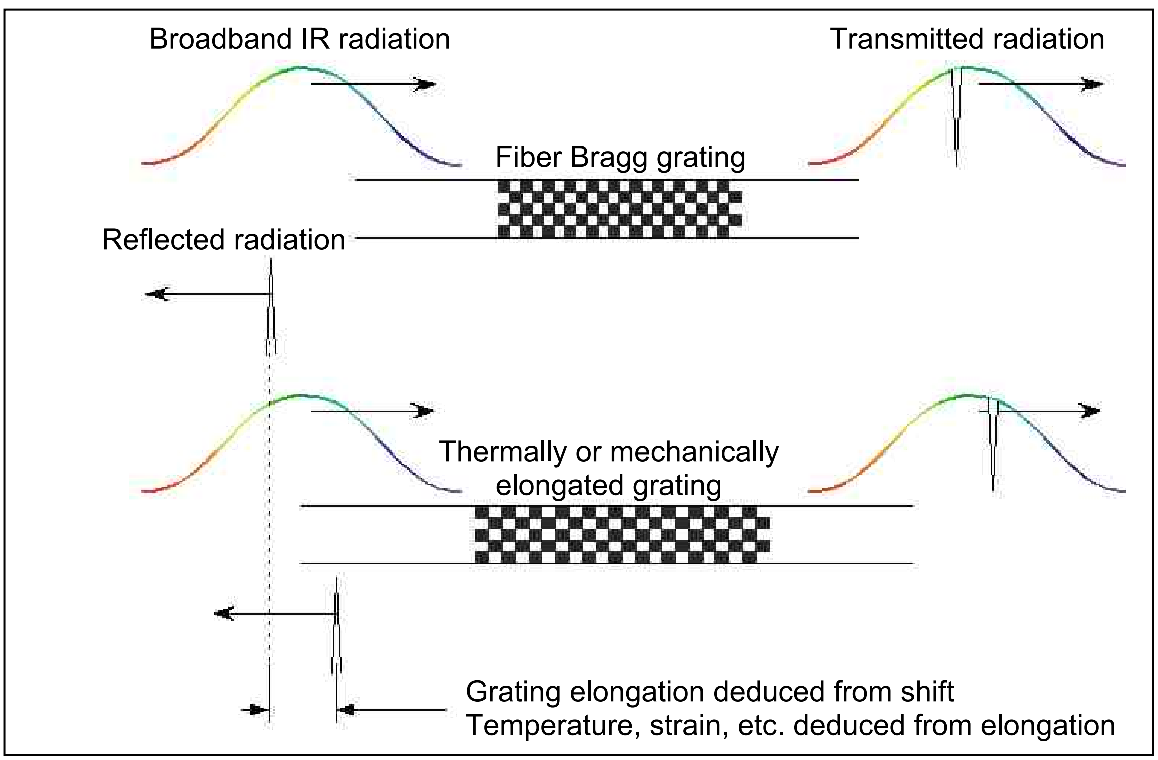

Figure 2. Principle of operation of a fiber Bragg grating measurements system.

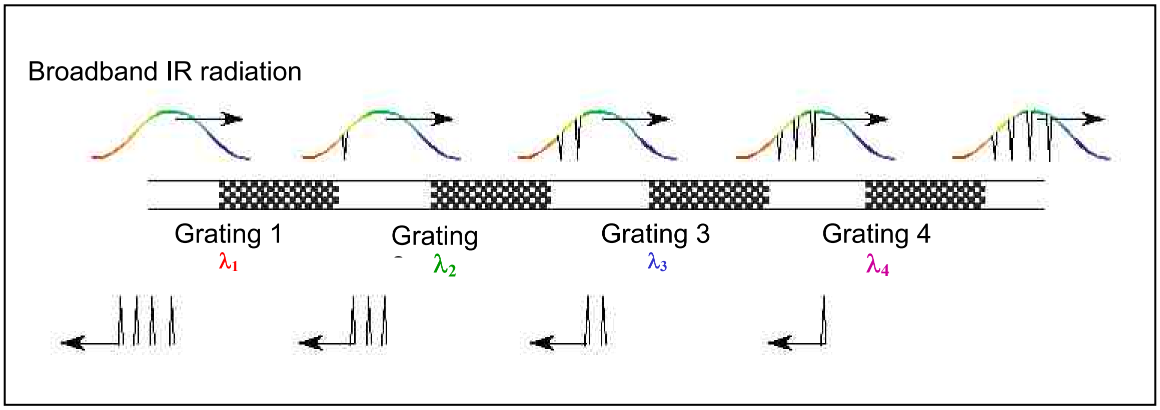

Figure 3. Method of multiplexing multiple sensors on a single optical fiber.

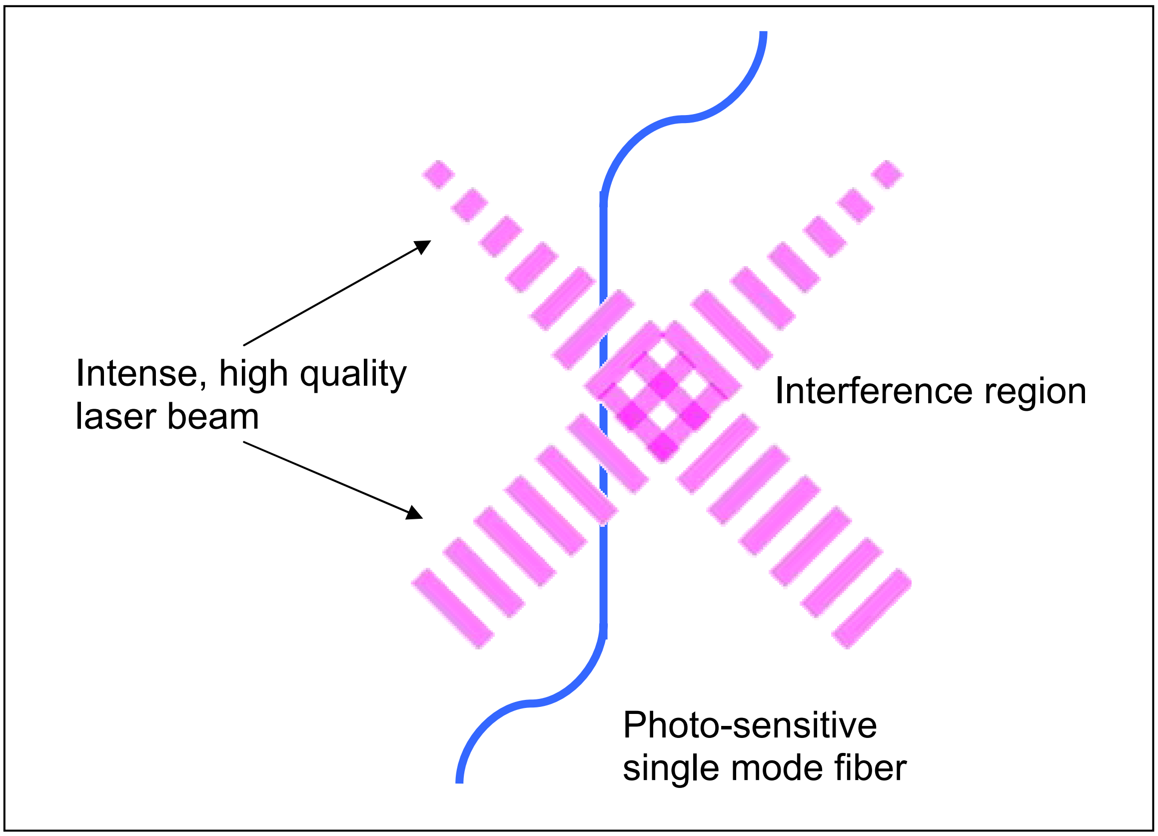

Figure 4. Production of fiber Bragg gratings by exposing photo sensitive single mode optical fibers to intense interfering laser beams.