Discover Magazine Awards for Technological Innovation (2000)

1) Name of the Innovation

Micromechanical landmine detector for humanitarian de-mining

2) Describe the innovation in few sentences.

This innovation is a novel, compact, low-cost landmine detector based on microcantilever sensing technology. Microcantilevers, which are much narrower than a human hair, can adsorb and react to chemicals of interest. It has been recently demonstrated that they can detect minute amounts (parts-per-trillion concentrations) of trinitrotoluene (TNT). Forces produced by heat-induced nano-scale explosions of adsorbed TNT molecules indicate the presence of a TNT source, such as a landmine. The beauty of this revolutionary technology is that it is extremely sensitive and selective, and it is capable of continuous operation because the microcantilevers regenerate themselves after each use.

3) How does it work?

Ironically, the device works by “fighting fire with fire.” TNT molecules floating in the air in the vicinity of an explosive get adsorbed onto a semiconductor material, which is specially machined into the shape of a cantilever (or diving board), about one tenth the diameter of a human hair. Each cantilever is typically 100 μm long, 20 μm wide, and 1 μm thick and has a mass of a few nanograms. When the semiconductor material is heated to a characteristic temperature, TNT molecules undergo “nanoexplosions,” explosions so small that they cannot be seen through a powerful microscope. The reverberation of the cantilever caused by an explosion is detected by an optical-beam deflection method with angstrom-scale resolution.

Even buried mines, especially those that have degraded over time and have become quasi-stable, insidiously release TNT vapors that permeate through the soil, reaching parts-per-trillion concentrations in their environs. The micromechanical landmine detector dexterously captures TNT molecules from the air by adsorption onto the cantilever surface and clearly identifies the TNT by exploiting its own explosive nature. The key to this device's exceptional sensitivity is a revolutionary micromechanical transducer, micromachined from single-crystal silicon with an implanted boron channel for controlled heating.

When the passage of an electric current causes the temperature of the cantilever to increase to the characteristic temperature of TNT (575^{o}C for 0.1 s), the adsorbed TNT molecules explode. Because the thermal mass of the cantilever is small, it can be heated to more than 700^{o}C in a millisecond with merely one microwatt of power. The transient vibrations due to nanoexplosions are detected by a diode laser beam focused on its apex, a technology similar to the way that a compact disc works, but 1000 times more responsive.

The sensitivity of the sensor is due to the cantilever's ability to respond to extremely small mechanical or thermal perturbations. Thus, nanoexplosions from less-than-picogram quantities of TNT are sensed quickly. The cantilever's response to explosive vapor is very specific, depending on the characteristic time and characteristic temperature required for initiation of nanoexplosions. By scanning an appropriate temperature range, many explosive molecules, including those with low vapor pressures such as the notorious plastic explosives (PTEN and RDX), can also be detected.

In contrast to other approaches based on chemical coatings, which exhibit rapid degradation in performance due to loss in integrity of the coating material(s), this innovation is at least 1000 times more sensitive and does not undergo degradation. In addition, this innovation is very simple and does not contain a radioactive source (as in the case of the electron-capture detector), or vacuum pumps (as in the case of mass spectrometers), or huge magnets (as in the case of nuclear magnetic resonance), or carrier gas (as in the case of gas chromatography).

4) **What problem did this innovation solve?**

A widespread need exists for humanitarian de-mining in many parts of the world. Current devices for locating landmines are expensive and require bulky, complex, and cumbersome equipment and trained personnel, making the technology unaffordable for humanitarian de-mining. None of the technologies currently available offer a clear path to the development of an extremely sensitive, miniature, and inexpensive device. To fulfill this need, a paradigm shift is essential. A mass-produced, low-cost device with excellent portability and low power requirements (like the transistor radio) is the key to humanitarian de-mining operations.

This innovation is a breakthrough in ultrasensitive detection of explosive vapors. It can be mass-produced using conventional techniques developed for integrated circuit (IC) technology and can be used with regular batteries or solar cell power.

Advantages of this technology:

- Novel and simple concept (no similar device has been demonstrated before)
- Excellent sensitivity and selectivity
- Does not use complicated or bulky equipment
- Miniature size; can be mass-produced with conventional IC technology
- Low power consumption
- Fast and continuous operation
- Can be operated by unskilled people in any part of the world

5) **Why is it important?**

Despite the clarion call of celebrities such as late Princess Diana and the award of a Nobel Peace Prize in 1997 (International Campaign to Ban Landmines and Jody Williams), daily losses of human lives and limbs continue due to lack of technological breakthroughs in humanitarian de-mining.

Unexploded ordnance remains a gruesome fact of life, endangering innocent civilians long after the fighting in which it was used is over. These dangerous remnants of often forgotten wars kill 26,000 innocent civilians a year. Countless more are maimed. Millions of acres of farmland lie abandoned in third-world countries due to mine infestation. These lands could be put to better use for feeding an ever-growing population. Even in European countries, millions of bombs and landmines left over from World War II still remain uncleared.

Current figures show that more than 110 million active mines are scattered over 64 countries. For every mine removed, 10 more are laid. Because mines can be manufactured at a cost of a few dollars per unit, and because they can be easily deployed, they are the weapons of first choice in almost every conflict. Mine removal is at least 1000 times more expensive than the cost of deployment. At the current rate of removal, it will take a few thousand years to remove all the mines deployed worldwide. In Afghanistan alone, assuming no additional mines are laid, it will take about 4000 years to remove all the mines! A similar situation exists in Angola and Cambodia, and in dozens of other countries as well.

With the high cost, the magnitude of the problem, and the slow pace of present-day de-mining operations, progress has been slow despite the toll in human suffering. This innovation is so simple and low in cost that it will tip the economics in favor of the mine-removal personnel. It is a simple technology that can be used in any corner of the world by local people without elaborate training. It consumes so little power that it can be operated with a battery or a photovoltaic cell.

6) **How will this innovation benefit the public or the general consumer?**

Unexploded ordnance and landmines are a bane in society, claiming the lives of many innocent people and maiming many others every minute. In third-world countries, where the population is largely agrarian, millions of acres of farmland lie wasted due to landmine infestation. The killing and maiming of innocent civilians cause enormous economic hardships and decreased quality of life, and impede general progress. Making this novel technology available to humanitarian de-mining operations will help in putting an end to the unnecessary human suffering and economic drain in countries ravaged by landmines. This will in turn promote prosperity and will increase the quality of life. In Angola alone, 1 out of 140 people (more than 80,000 individuals) are landmine amputees, most of them little children. Fewer than 10% ever receive prosthetic limbs.

Explosive detection by microcantilevers represents a totally new technology for chemical detection. This concept allows the mass production of rugged, inexpensive, yet highly sensitive detectors for humanitarian de-mining. In addition, this innovation will also have applications in law enforcement. For example, in the United States almost 2000 bombings occur every year, killing about 150 people and injuring about 600. This innovation will find applications in

- screening large numbers of people, vehicles, and luggage;
- monitoring weapons, hidden explosives, and ammunition;
- protecting special infrastructures and government buildings;
- forensic applications (post-blast analysis and evidence identification); and
- monitoring and remediation of contaminated sites (defense and industrial).

In addition, this revolutionary, low-cost innovation will have wide impact in medical and industrial civilian sectors with applications including diagnostics, process control, environmental monitoring, and energy conservation. This technology provides a new paradigm for future development of novel chemical sensors based on nano-scale science and technology (sub-nano-scale energy transfer in chemical reactions). For example, novel real-time heat-induced chemical reactions can be used in clinical and forensic applications. Many new medical and consumer products as well as safety devices can be developed using this platform, thus improving the quality of life with modest investments.

7) **When was this developed?**

The device was developed in 1999 (based on three years of research). The first demonstration of a working device was achieved in December 1999.

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Information:

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http://www.ornl.gov/news

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