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A Portable SAW/GC Non-Intrusive Inspection System

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abstract

Portable non-intrusive inspection systems to identify and quantify the presence of contraband at ports of entry, on personnel, within vehicles, and aboard cargo in ships and aircraft are needed. A low cost, easy to use, mobile trace analysis system which can be used to detect currency, explosives, firearms & munitions, hazardous chemicals, and general forensic screening is described in this paper.

The portable inspection system to be described is part of a pilot program to develop a solid state vapor analysis system using surface acoustic wave (SAW) sensors and fast gas chromatography. SAW/GC technology needs no high voltages, utilizes essentially all solid state devices, and involves no radioactive or hazardous materials. SAW/GC systems have demonstrated dynamic ranges greater than 100,000 and the ability to detect vapors from contraband at the part per billion level.

The fast SAW/GC inspection system identifies and quantifies vapor or particulate trace materials collected from ambient environments in near real time (< 10 seconds). The system is able to identify known vapor signatures and is equipped with a non-intrusive preconcentrator which does not require contact with the inspected object. The development of quantitative testing protocols and methods for drugs, currency, organo-phospate agents, and volatile organic compounds will be presented.

Quantitative testing of the new SAW/GC technology has shown high selectivity, specificity, and 1-10 picogram sensitivity for drugs of abuse such as cocaine, marijuana, and heroin. Results achieved with prototype systems incorporating vapor/particulate detection using low voltage solid-state surface acoustic wave (SAW) vapor sensors, high speed (<10 second) gas chromatography, and a notebook size data acquisition system with the capability of unattended recording and remote control, will be presented. The advantages are (1) portability (2) low voltage solid state sensor and electronics (3) high sensitivity and tunable specificity and (4) a simple easy to use graphical interface for un-skilled inspection personnel. The development of an inspection system costing less than $20,000 will benefit drug interdiction efforts.

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.A Portable SAW/GC Non-Intrusive Inspection System

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Introduction

This paper describes research on a fast portable non-intrusive inspection system to identify and quantify the presence of contraband at ports of entry, on personnel, within vehicles, and aboard cargo in ships and aircraft. The system utilizes fast GC vapor analysis with a new type of Surface Acoustic Wave (SAW) detector technology. The objective of this research project[1] is to develop a low cost, easy to use, mobile trace analysis system which can be used to detect currency, explosives, firearms & munitions, and hazardous chemicals.

System Description

Prototype inspection systems[2], as shown in Figure 1, are currently being used in field trials and data gathering experiments. The SAW/GC portion of the system is contained within a handheld module as shown. Support for the system (He carrier gas and electrical power) as well as a laptop computer and Windows® user interface is contained within a small suitcase.

The SAW/GC system requires no high voltages, utilizes essentially all solid state devices, and involves no radioactive or hazardous chemicals. The prototype SAW/GC system has demonstrated dynamic ranges greater than 100,000 and the ability to detect and analyze vapors from contraband at the part per billion level (picograms/liter). The SAW/GC inspection system is fast and accurate. It identifies and quantifies vapor or particulate trace materials collected from ambient environments in near real time (< 10 seconds). Typically only 10 cc of ambient air needs to be collected with a 100 ccm inlet flow prior to each analysis.

Figure 1- Portable SAW/GC Inspection System.

Specificity and selectivity is based upon thermal management and material vapor pressure. The system is able to identify and alarm upon known vapor signatures and is non-intrusive because it does not require contact with the inspected object. At this time test methods and

[1] This work was sponsored by the U.S. Army, Non-Intrusive Inspection Development, Evaluation, and Transition Management Structure, Contract No. DAAB10-95-C-0009.

[2] Partial support for early prototype inspection systems was provided by the Locheed Marrietta Corporation, Ocean System and Sensor Division, Syracuse, New York.

protocols have been developed for quantitative testing of vapor from drugs, currency, organo-phospate agents, and volatile organic compounds.

Technology Description

The basic operation of the SAW/GC system is illustrated in Figure 2. The system utilizes a two position, 6 port GC valve to switch between sampling and injection ports. In the sample position environmental air is passed through an optional inlet preconcentrator and then through a sample loop trap.

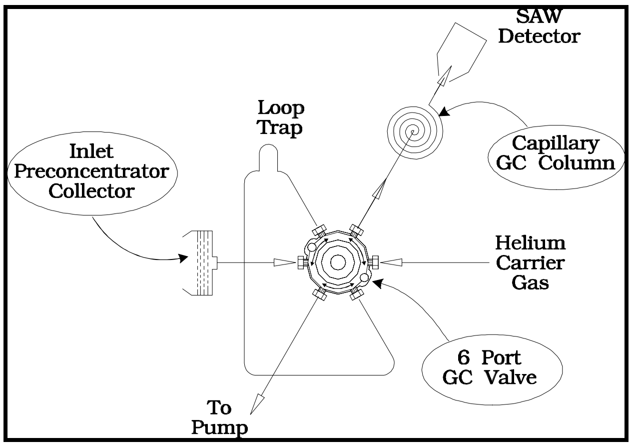

Figure 2- SAW/GC System Description.

The preconcentrator provides the system with the ability to concentrate inlet with high flow. The function of the loop trap is to retain contraband aerosols materials when in the sample position. During sampling, helium carrier gas flows down a capillary column, through a nozzle, and onto the surface of a temperature controlled SAW resonator crystal[3] as shown in Figure 3.

Switching the valve to the inject position causes helium carrier gas to flow backwards through the loop trap and onto the column. After the valve is switched into the inject position the loop trap is rapidly heated to 200^{o}C causing the trapped contraband materials to be released into the GC column. The temperature of the GC column is linearly raised to 250^{o}C over a 5-10 second time and this causes the contraband materials to travel down the column and exit at a time dependent upon the vapor pressure and column absorption of each vapor.

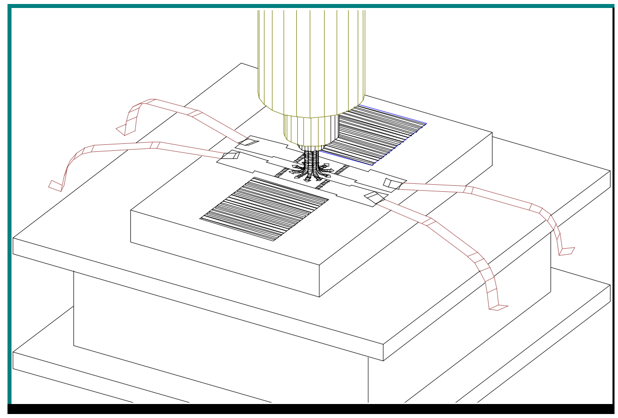

Figure 3- Surface Acoustic Wave GC Detector.

The SAW resonator represents a new class of GC detector. Condensable vapors as they exit the GC column are focused and trapped on the surface of the resonator and cause a change in the characteristic frequency of the crystal resonator. The inherent frequency stability of the resonator, typically $1x10^{-10}\bullet F_o$, results in femtogram sensitivity. The adsorption efficiency of each vapor is a function of the surface temperature and the material vapor pressure. By operating the crystal at different temperatures, detection can be made specific to vapors based upon their characteristic vapor pressure. Also, since the crystal acts as a micro-balance it integrates the total amount of condensed vapor and to obtain a familiar chromatogram plot of flux Vs retention time, the derivative of frequency Vs time is calculated. This is in contrast to the operation of a conventional GC detector which detects the flux and integral calculations are required to obtain the amount of each material present.

Field Test Results

[3] United States Patent No. 5,289,715, Vapor Detection Apparatus and Method Using an Acoustic Interferometer.

At the present time prototype SAW/GC vapor analysis systems are being field tested under many different conditions. These tests include monitoring of VOC contamination of soil and groundwater at DOE SuperFund sites and as aids in training canines to detect drugs of abuse.

In a recent field test, a prototype SAW/GC system participated in a Detection Assessment Program[4] sponsored by the U.S. Government. The instrument was first calibrated using a vapor generator. A typical scale factor for cocaine vapor was 17 Hz/pg. Large plywood boxes, 4 x 4 x 6 feet (2700 cu liters) as shown in Figure 4, were used to simulate cargo containers.

In one test a 1 kg brick of cocaine was placed at the bottom of the container and al-

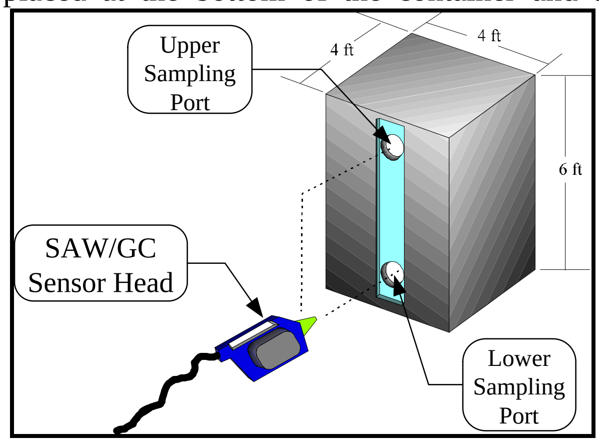

Figure 4- Plywood box with vinyl liner containing cocaine vapor source.

lowed to equilibrate for 24 hours. Following a testing protocol, the room was sampled first and found to contain cocaine vapors but at a very low level. Next the container was tested. Ten second chromatograms of vapor samples taken at the top and bottom holes of the container are shown in Figure 5 and Figure 6. Sampling 10 cc of ambient air at the lower opening indicated cocaine vapors with a frequency shift of approximately 4000 Hz while at the top of the

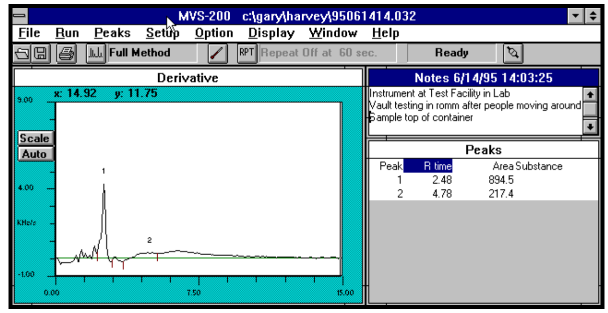

Figure 5-Analysis of vapors taken at top of container.

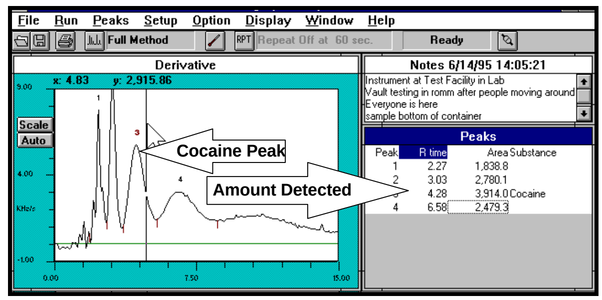

Figure 6- Analysis of vapors taken at bottom of container.

container less than 100 Hz of frequency shift was observed. The results were quite repeatable and are consistent with vapor characteristics observed with other non-volatile materials. The detected frequency shifts are converted to cocaine vapor concentration in pg/liter factor in Figure 7.

The actual measurements show a concentration less than 58 pg/liter at the top and a

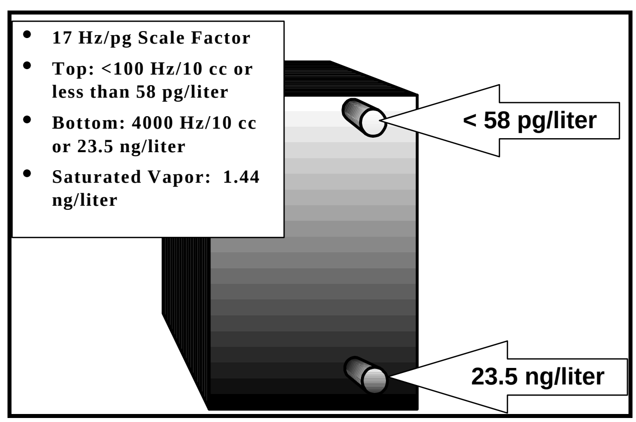

Figure 7-Summary of vapor concentrations at top and bottom of container.

concentration of 23.5 ng/liter at the bottom.

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[4] Cocaine and Heroin Vapor/Particle Detection System Assessment Program, USCS93100, Rev. D (9-30-94).

This more than saturated cocaine vapor concentration of 1.442 ng/liter at 20^{o}C. Within the 10 cc sample taken by the inspection system, approximately 235 pg of cocaine was detected.

It is interesting to note that the cocaine vapor concentration at the bottom of the container is considerably higher than saturated vapor at room temperature (1.44 ng/liter) and that a considerable gradient exists within the container even after waiting 24 hours before performing the test. It is speculated that the diffusion constants for non-volatile materials are so low that equilibration does not occur except over extremely large time periods.

Recent chromatography improvements in the SAW/GC have shown it is possible to quickly detect cocaine vapor at the picogram per liter level using only a small sample of the ambient air. Cocaine specificity and selectivity for the inspection system has been optimized. Current systems are able to achieve 2000 plate cocaine peaks as shown in Figure 8. In this chromatogram a cocaine peak with an area of 7386 Hz (434 pg) and a retention time of 7.1

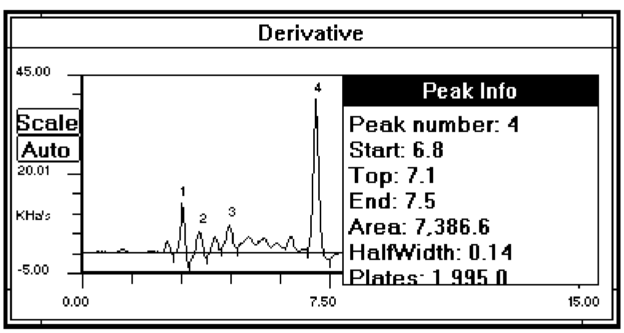

Figure 8-GC Method Optimized for cocaine detection.

seconds is shown to heave a half width of only 140 milliseconds. Because the SAW detector integrates the sample directly it has no dead volume and can readily detect picogram and even femtogram vapor concentrations.

Conclusions

A new type of fast chromatography system, the SAW/GC, has been developed for analyzing vapors associated with volatile and non-volatile materials. Tests have shown that vapor detection is a viable non-intrusive method of detection. Portable non-intrusive inspection systems to identify and quantify the presence of contraband are now being field tested.

Current research goals are to reduce the size and cost while improving the performance of the inspection system. Future SAW/GC inspection systems will contain a sunlite readable user display as well as a high flow front end preconcentrator for sampling larger volumes of ambient air.

A low cost, easy to use, mobile trace analysis system which can be used to detect currency, explosives, firearms & munitions, hazardous chemicals, and general forensic screening will benefit many government and commercial fields.

Acknowledgments

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