# Chemical Microsystem based on Vertical Integration of Sensor Array and CMOS Circuit

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*ABSTRACT: Results of a 6-month IREE research trip to ETH Zurich in Switzerland are presented. During the trip, the researcher performed gas phase experiments with a chemical microsensor platform to explore and optimize its sensitivity and limit of detection. The results are to be presented at the IEEE Transducers 2009 Conference in Denver, Colorado. The researcher was immersed in Swiss culture during his stay, took a German course at ETH Zurich, and developed an international network of collaborators.*

## INTRODUCTION

The current NSF award 0601467 has been awarded to the Georgia Institute of Technology to investigate and optimize a mass-sensitive chemical microsensor platform for detection of volatile organic compounds in air. Work has been carried out on the design, fabrication, and application testing of resonant chemical sensors, which respond to mass changes caused by the adsorption and desorption of a gas-phase analyte into sensitive films covering the resonator structures. To improve the limit of detection, the sensor platform explores in-plane vibration mode shapes of disk-type microresonators. These vibration modes experience reduced damping in an air environment, thus yielding a better frequency stability and limit of detection. The resonant microsensors are interfaced with appropriate circuitry through a vertical integration scheme, which ensure that the resonant sensors are continuously operated in the desired in-plane mode shape.

The IREE program gave the researcher the opportunity to test the aforementioned microsensors in a custom-made gas manifold at the Bioelectronics Laboratory (BEL) at ETH Zurich, which had been used previously in other research to expose chemical microsensors to controlled analyte concentrations [1-4]. The IREE program gave the awardee the opportunity to perform research in an international setting in Switzerland, working not only with Swiss researchers but also with ones from Germany and Italy. The PI had previously been associated with the lab which hosted the station. The Bioengineering Laboratory was established in 2008 as a successor to the influential Physical Electronics Laboratory (PEL) at ETH Zurich. The lab is headed by Prof. Andreas Hierlemann, a widely cited and world renown expert in chemical and biological sensors.

The researcher who participated in the IREE program was Stuart Truax, a graduate student at Georgia Tech, who had conducted research under the NSF award for two years prior to his trip. He had research experience with the microsensor platform and several publications to his credit. He also has an interest in study abroad and had studied German for his trip. His trip spanned from July 9, 2008 to December 31, 2008. The research conducted on the trip so far resulted in a conference paper, which has been accepted to the Transducers 2009 Conference in Denver, Colorado. Work on a journal paper based on the research is also underway. During his time in Switzerland, Mr. Truax took a course offered by the ETH in German.

## RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

During the international research experience, the researcher carried out a research program consisting of:

1. Characterization of mass-sensitive microsensor arrays that had been previously developed and fabricated at the Georgia Institute of Technology.
2. Characterization of a novel mutlisensor microsystem that combines two different chemical sensing principles (mass-sensitive and impedance) in a single sensor platform.

This program was carried out in the context of the ongoing research project ECS 0601467. The primary goal of this project is **to develop chemical sensing microsystems based on a vertical integration of microfabricated sensor arrays and CMOS circuitry**. The microsystem integration program covers the (i) design and fabrication of mass-sensitive chemical sensor arrays, and of their driving and signal conditioning circuitry, (ii) the necessary process development for the vertical integration and system packaging, (iii) the localized deposition of different recognition membranes onto the transducer elements of the array, and (iv) relevant application testing of the microsystem. By proper choice of the transducer types and the set of recognition membranes, such a microsystem can be tuned to a wide range of chemical and biochemical sensing applications in both gaseous and liquid environment. In the ongoing program, the detection of volatile organic compounds (VOCs) in air and especially the separation of chemically related VOCs as a performance measure is investigated.

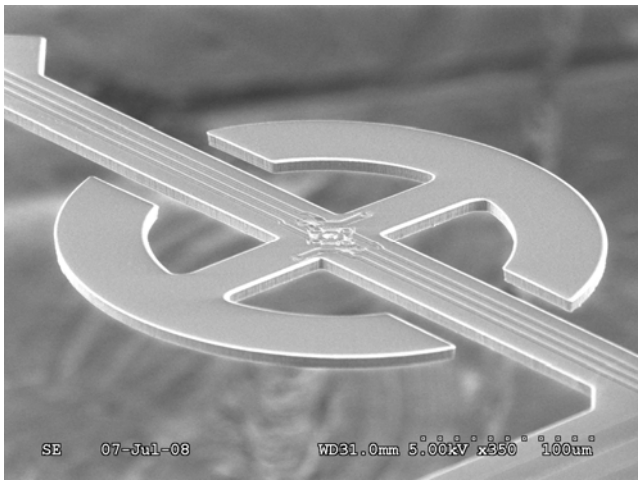


*Figure 1: SEM micrograph of resonant disc microsensor. Disc radius is 150 µm.*

The IREE gave us the opportunity to thoroughly characterize the developed microsensors in a customized gas mixing system. The microsensor array characterization carried out by the researcher at the BEL lab involved: the investigation of sensitive layer deposition onto the microsensors, and the application testing of the microsensors using the gas manifold. These two research aspects directly correspond to points (iii) and (iv) listed above. The resonant microsensor in Fig. 1 was coated using sensitive layers consisting of (poly)isobutylene (PIB) and (poly)dimethylsiloxane (PDMS).

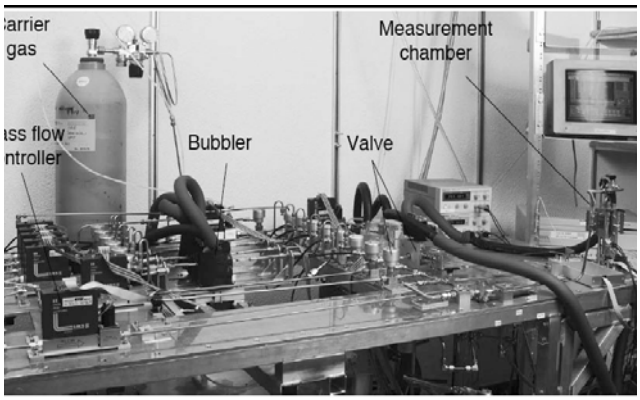


*Figure 2: Gas mixing manifold at ETH Zurich's BEL lab.*

The functionalized sensors were then placed in the gas mixing manifold shown in Fig. 2., where controlled streams of analyte loaded gas were passed over the sensors to measure their sensitivities and limits of detection.

The gas manifold system consisted of a carrier gas supply which was connected to several analyte bubblers. The analyte bubblers contained liquid phase volatile organic compounds (VOCs) kept at a specific temperature which was controlled by a thermostabilized bath. Digitally controlled flows of carrier gas were passed through the

bubblers, resulting in a vapor mixture containing a controlled concentration of analyte. The mixture was further diluted before being passed to a measurement chamber where the sensor being tested was located. Upon exposure the sensors undergo a downward frequency shift, from which sensitivity and limit of detection data can be extracted.

Fig. 3 shows an example of a sensor response to various concentrations of toluene vapor. The research conducted the ETH Zurich's BEL laboratory allowed the researcher to experiment with different sensor designs and geometries to better understand which ones yield the best limit of detection. Also, initial tests were conducted with a novel multisensor microsystem. Further testing is needed before the microsystem can be fully evaluated. Results of the microsensor characterization will be presented and published in the Proceedings of the IEEE Transducers 2009 Conference [5].

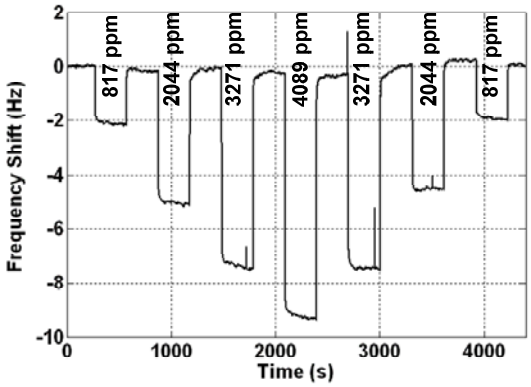


*Figure 3. Frequency change of resonant microsensor upon exposure to toluene vapor.*

During his stay in Switzerland, the researcher also participated in the host lab's daily activities by attending weekly group meetings, aiding research, attending department sponsored outings, and having lunch daily with his labmates. The researcher had a chance to attend and present at Eurosensors 2008 in Dresden, Germany with members of his host lab. This allowed him interact with members of the European microsystem community, and form contacts and networks abroad

## BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

By travelling to Switzerland, the researcher was given exposure to the academic and professional practices of Switzerland, which is representative of other German-speaking countries. ETH Zurich's BEL lab, where the researcher spent his time, is the home of the startup company Zurich Instruments. This gave the researcher insight into how the Swiss startup process and academic commercialization differs from its U.S. equivalent. The researcher also took an introductory German class at ETH Zurich, which enhanced his education in Germanic culture and allowed him to experience Swiss higher education firsthand. Witnessing firsthand how Swiss and European research projects are conducted (given their different funding structures) was also very informative for researcher. In September 2008, the researcher attended Eurosensors 2008 in Dresden, Germany with members of his host lab, which further introduced him to the European microsystem's community.

The IREE award allowed the PI and his team to perform chemical measurements in a gas mixing system that is currently not available at Georgia Tech. Based on the research results, Prof. Hierlemann of ETH Zurich and the PI are currently looking into the possibility of future joint research programs.

## DISCUSSION AND SUMMARY

The researcher performed gas phase experiments of a chemical microsensor platform to explore and optimize its sensitivity and limit of detection. A custom-built gas manifold system at the ETH Zurich's BEL laboratory allowed him to conduct application testing of devices designed and fabricated at the Georgia Institute of Technology. The results are to be presented at the IEEE Transducers 2009 Conference in Denver, Colorado. The researcher was immersed in Swiss culture during his stay, took a German course at ETH Zurich, and developed an international network of collaborators.

During preparation for the trip, it became clear that VISA clearances would delay the beginning of the trip. The researchers would like to make a Best Practice recommendation that all future awardees prepare the necessary VISA applications 2-3 months ahead of time to avoid any delay. This should only be an issue for trips exceeding 90 days or for trips to countries requiring special VISA clearances.

## ACKNOWLEDGEMENTS

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## BRIEF BIOGRAPHIES OF RESEARCHERS

**Stuart Truax** received the B.S. and M.S. degrees in electrical engineering from the Georgia Institute of Technology in 2005 and 2006, respectively. He is currently pursuing his Ph.D. in electrical engineering at the Georgia Institute of Technology. His research focuses on the application of resonant microstructures to chemical sensing.

**Oliver Brand** is an Associate Professor in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. He received his diploma degree in Physics from Technical University Karlsruhe, Germany in 1990 and his Ph.D. degree from ETH Zurich, Switzerland in 1994. From 1995 to 1997, he worked as a postdoctoral fellow at the Georgia Institute of Technology. From 1997 to 2002, he was a lecturer at ETH Zurich in Zurich, Switzerland and deputy director of the Physical Electronics Laboratory (PEL).

Dr. Brand has co-authored more than 140 publications in scientific journals and conference proceedings. He is a co-editor of the Wiley-VCH book series *Advanced Micro and Nanosystems*, a member of the editorial board of *Sensors and Materials*, a member of the technical program and steering committees of the *IEEE MEMS Conference*, and has served as General Co-Chair of the *2008 IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2008)*. Dr. Brand is a

senior member of the IEEE and a co-recipient the *2005 IEEE Donald G. Fink Prize Paper Award*. His research interests are in the areas of silicon-based microsystems, microsensors, MEMS fabrication technologies, and microsystem packaging.