

satellite position at the vertex. In an SBAS based upon the conical domain model, fits of delay on a grid of IGP are replaced with fits inside cones, each having a GPS satellite at its vertex. A user (e.g., an airplane in flight) within a given cone evaluates the delay to the satellite directly, using (1) the IPP coordinates of the line of sight to the satellite and (2) broadcast fit parameters associated with the cone.

In the context of SBAS, the conical-domain model suffers from one major limitation: each fit is comprised of relatively few measurements. Since the reliability of a fit depends upon the number of its measurements, a small number of fit measurements represent a threat to the integrity of the delay estimates based upon the fit. The multi-cone model, in which measured signals from multiple satellites are incorporated into each delay estimate, has been conceived as a means of obtaining the benefits of the conical-domain model without suffering a potentially serious loss of integrity.

The basic idea of the multi-cone model is to adapt the conical-domain model to obtain fits on an ionospheric grid. The adaptation involves multiple stages. In the first stage, the conical-domain model is used to obtain an estimate of the slant delay for each ray path

that connects a visible satellite to a specified IGP. This requires a separate fit for each satellite. Each delay estimate may be regarded as a pseudo-measurement of a signal for the satellite in question. In the second stage, the conical-domain model is turned upside down in the sense that instead of creating a cone of measurements having a satellite at its vertex and multiple receivers at its base, one forms a cone having a single receiver at the vertex and performs a fit of a set of pseudo-measurements within this cone (see Figure 1).

This process is repeated until fit parameters have been determined for cones at each IGP in a grid. It is then possible to evaluate the slant delay for any ray path that passes through both a user's position and an IGP. To evaluate the slant delay to a satellite of immediate interest from any arbitrary user position, the user first locates the IPP of the signal from that satellite and then identifies the four IGP at the corners of the grid cell that contains this IPP. The estimates of the slant delays for the ray paths through each of these four IGP can then be interpolated to obtain the slant delay between the user's position and the satellite of immediate interest (see Figure 2).

This estimate formally converges to the correct value in the limit as the den-

sities of participating GPS receivers and GPS satellites become very large and, simultaneously, grid cells become more nearly infinitesimal. It should be noted that the user's slant delay estimate contains information from all the signals that have been used to define the cones at the four interpolation IGP (in contrast to fitting only data from signals emitted by the satellite of immediate interest as in the original conical-domain approach). The use of additional information in evaluating each fit serves to improve the integrity of the delay estimate while preserving the accuracy of the conical domain model.

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## High-Sensitivity GaN Microchemical Sensors

**This innovation enables remote detection of chemical/biological toxins in the air.**

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Systematic studies have been performed on the sensitivity of GaN HEMT (high electron mobility transistor) sensors using various gate electrode designs and operational parameters. The results here show that a higher sensitivity can be achieved with a larger  $W/L$  ratio ( $W$  = gate width,  $L$  = gate length) at a given  $D$  ( $D$  = source-drain distance), and multi-finger gate electrodes offer a higher sensitivity than a one-finger gate electrode. In terms of operating conditions, sensor sensitivity is strongly dependent on transconductance of the sensor. The highest sensitivity can be achieved at the gate voltage where the slope of the transconductance curve is the largest.

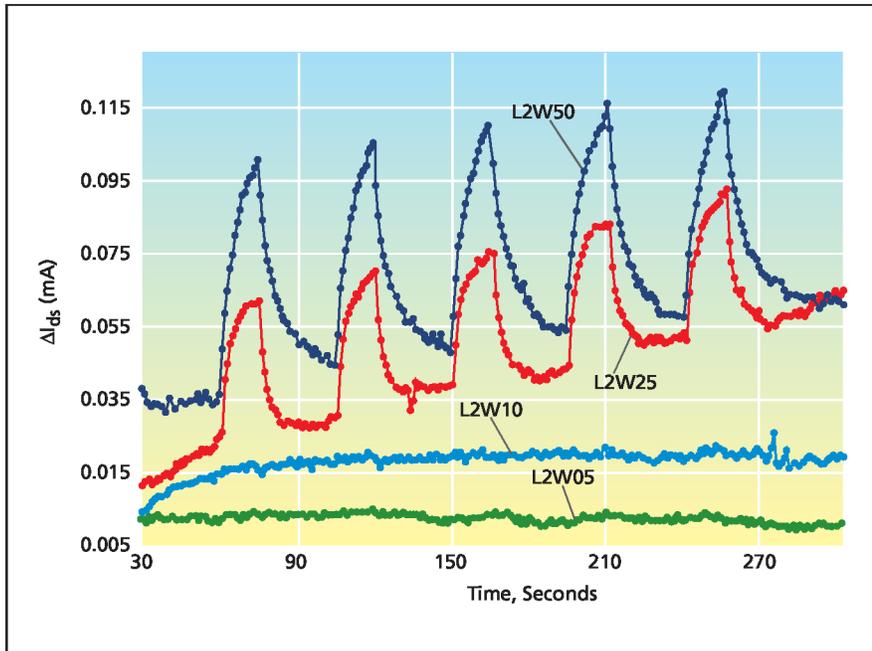
While GaN-based microchemical sensors have shown very promising performance characteristics, there has not been much understanding on how sen-

sor sensitivity can be engineered or improved. This work provides critical information about how the gate electrode of a GaN HEMT, which has been identified as the most sensitive among GaN microsensors, needs to be designed, and what operation parameters should be used for high sensitivity detection.

The figure shows  $I_{ds}$  (source-drain current) response to  $SF_6$  exposures measured using the GaN HEMT sensors fabricated with  $W = 5, 10, 25,$  and  $50 \mu m$  at  $L = 2 \mu m$ . The sensors clearly demonstrate a higher sensitivity with an increasing gate width.  $I_{ds}$  response measured using GaN HEMT sensors fabricated with  $L = 2, 4,$  and  $8 \mu m$  at  $W = 50 \mu m$  and with  $L = 2 \mu m$  at  $W = 25 \mu m$ ; (in these sensors the source-drain distance is  $DS = L + 4 \mu m$ ) show decreasing sensitivity with an increasing gate length.

Comparison between L4W50, L8W50 and L2W25 sensors, which correspond to DS8W50, DS12W50, and DS6W50 respectively, indicates that the sensor sensitivity is not simply proportional to  $I_{ds}$  or  $W/L$  (or  $W/DS$ ). The higher sensitivity achieved with the L2W25 sensor compared to the L4W50 sensor indicates that the shorter gate length plays a significant role. The results shown here suggest that sensor sensitivity is not simply proportional to the size of the gate electrode or the amount of  $I_{ds}$  of the sensor, and that a short gate length and a source-drain distance are important factors in determining the sensitivity of the sensor.

The robust, high-sensitivity GaN HEMT chemical sensors can be applied to NASA missions including *in-situ* detection of signatures of extraterrestrial life and *in-situ* planetary atmosphere



$I_{ds}$  Source-Drain Current Response to  $\text{SF}_6$  Exposures was measured using the GaN HEMT sensors fabricated with  $W = 5, 10, 25,$  and  $50 \mu\text{m}$  at  $L = 2 \mu\text{m}$ . The sensors clearly demonstrate a higher sensitivity with an increasing gate width.

analysis during planetary exploration. The sensors can be also used for health and habitat environmental monitoring for astronauts during manned missions. Due to the high thermal and chemical stability and excellent radiation hardness, GaN HEMT sensors can operate in all planetary conditions, which has not been possible for the conventional Si-based sensors. This innovation can offer a key capability for future NASA missions in extreme environments including Venus surface missions and Europa and Titan flagship missions. These micro GaN chemical sensors will be beneficial for Mars astrobiology field labs, comet nucleus sample returns, Titan in-situ, Europa surface and subsurface, and giant planet deep probe missions.

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## On the Divergence of the Velocity Vector in Real-Gas Flow

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A theoretical study was performed addressing the degree of applicability or inapplicability, to a real gas, of the occasionally stated belief that for an ideal gas, incompressibility is synonymous with a zero or very low Mach number. The measure of compressibility used in this study is the magnitude of the divergence of the flow velocity vector [ $\nabla \cdot \mathbf{u}$  (where  $\mathbf{u}$  is the flow velocity)]. The study involves a mathematical derivation that begins with the

governing equations of flow and involves consideration of equations of state, thermodynamics, and fluxes of heat, mass, and the affected molecular species. The derivation leads to an equation for the volume integral of  $(\nabla \cdot \mathbf{u})^2$  that indicates contributions of several thermodynamic, hydrodynamic, and species-flux effects to compressibility and reveals differences between real and ideal gases. An analysis of the equation leads to the conclusion

that for a real gas, incompressibility is not synonymous with zero or very small Mach number. Therefore, it is further concluded, the contributions to compressibility revealed by the derived equation should be taken into account in simulations of real-gas flows.

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## Progress Toward a Compact, Highly Stable Ion Clock

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There was an update on the subject of two previous NASA Tech Briefs articles: "Compact, Highly Stable Ion Clock" (NPO-43075), Vol. 32, No. 5 (May 2008), page 63; and "Neon as a Buffer Gas for a Mercury-Ion Clock" (NPO-42919), Vol. 32, No. 7 (July 2008), page 62. To recapitulate: A developmental miniature mercury-ion clock has stability comparable to that of a hydrogen-maser clock. The ion-handling components are housed in a sealed vacuum tube,

wherein a getter pump maintains the partial vacuum, and the evacuated tube is backfilled with mercury vapor in a neon buffer gas.

There was progress in the development of the clock, with emphasis on the design, fabrication, pump-down, and bake-out of the vacuum tube (based on established practice in the traveling-wave-tube-amplifier industry) and the ability of the tube to retain a vacuum after a year of operation. Other develop-

ments include some aspects of the operation of mercury-vapor source (a small appendage oven containing HgO) so as to maintain the optimum low concentration of mercury vapor, and further efforts to miniaturize the vacuum and optical subsystems to fit within a volume of 2 L.

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