

## On-Wafer Measurement of a Silicon-Based CMOS VCO at 324 GHz

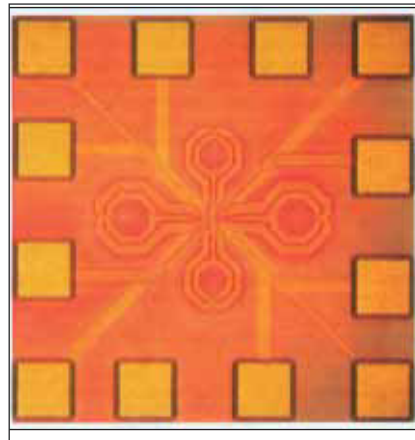
**Compact, low-power, electronically tunable submillimeter-wave local oscillators are now feasible.**

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The world's first silicon-based complementary metal oxide/semiconductor (CMOS) integrated-circuit voltage-controlled oscillator (VCO) operating in a frequency range around 324 GHz has been built and tested. Concomitantly, equipment for measuring the performance of this oscillator has been built and tested. These accomplishments are intermediate steps in a continuing effort to develop low-power-consumption, low-phase-noise, electronically tunable signal generators as local oscillators for heterodyne receivers in submillimeter-wavelength (frequency > 300 GHz) scientific instruments and imaging systems. Submillimeter-wavelength imaging systems are of special interest for military and law-enforcement use because they could, potentially, be used to detect weapons hidden behind clothing and other opaque dielectric materials. In comparison with prior submillimeter-wavelength signal generators, CMOS VCOs offer significant potential advantages, including great reductions in power consumption, mass, size, and complexity. In addition, there is potential for on-chip integration of CMOS VCOs with other CMOS integrated circuitry, including phase-lock loops, analog-to-digital converters, and advanced microprocessors.

The 324-GHz CMOS VCO (see figure) was designed and fabricated according

to the design rules of 90-nm-gate-length CMOS technology. However, it was nec-



This **CMOS Integrated Circuit** includes a VCO that generates four signals in phase quadrature at a fundamental frequency of about 81 GHz. The four 81-GHz signals are rectified and superposed to obtain a signal at 324 GHz.

essary to follow a somewhat unconventional approach because it is impossible to make a 90-nm-gate-length CMOS circuit oscillate at a frequency greater than about 170 GHz. The essence of the approach followed here is to generate a 324-GHz signal as a fourth-harmonic signal through linear superposition of four phase-delayed, rectified 81-GHz fundamental signals: Two cross-coupled 81-GHz VCO cores generate quadrature outputs at relative phases of 0°, 90°,

180°, and 270°. These four signals are rectified by class-B amplifiers, and the outputs of the amplifiers are combined. The fundamental-to-harmonic power-conversion efficiency is significantly greater than that of traditional harmonic generation through exploitation of nonlinear circuit characteristics. Moreover, the phase noise of the output signal is less than that of traditional harmonic generation because the phase noise is limited to that of the fundamental signal.

A custom on-wafer probe was developed for measuring the performance of the 324-GHz CMOS VCO. The probe includes a unique coplanar-waveguide/coaxial-cable/waveguide transition. The probe contacts are spaced at 100  $\mu\text{m}$  — a distance chosen to match the pitch of the contact pads on the CMOS VCO chip. The probe has been used to measure the phase noise, frequency of oscillation, and scattering parameters of the VCO at frequencies up to 340 GHz.

*This work was done by Lorene Samoska, King Man Fung, and Todd Gaier of Caltech; Daquan Huang, Tim Larocca, and M. F. Chang of the University of California, Los Angeles; Richard Campbell of Portland State University; and Michael Andrews of Cascade Microtech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45494*

## Group-III Nitride Field Emitters

**Growing group-III nitride films spontaneously split into columns.**

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Field-emission devices (cold cathodes) having low electron affinities can be fabricated through lattice-mismatched epitaxial growth of nitrides of elements from group III of the periodic table. Field emission of electrons from solid surfaces is typically utilized in vacuum microelectronic devices, including some display devices. The present field-emission devices and the method of fabricating them were developed to satisfy needs to reduce the cost of fabricating field emitters, make them compatible

with established techniques for deposition of and on silicon, and enable monolithic integration of field emitters with silicon-based driving circuitry.

In fabricating a device of this type, one deposits a nitride of one or more group-III elements on a substrate of (111) silicon or other suitable material. One example of a suitable deposition process is chemical vapor deposition in a reactor that contains plasma generated by use of electron cyclotron resonance. Under properly chosen growth condi-

tions, the large mismatch between the crystal lattices of the substrate and the nitride causes strains to accumulate in the growing nitride film, such that the associated stresses cause the film to crack. The cracks lie in planes parallel to the direction of growth, so that the growing nitride film becomes divided into microscopic growing single-crystal columns. The outer ends of the fully-grown columns can serve as field-emission tips. By virtue of their chemical compositions and crystalline structures,