the columns have low work functions and high electrical conductivities, both of which are desirable for field emission of electrons.

From examination of transmission electron micrographs of a prototype device, the average column width was determined to be about 100 nm and the sharpness of the tips was determined to be characterized by a dimension somewhat less than 100 nm. The areal density of the columns was found to about 5×10^9 cm^{-2} — about 4 to 5 orders of magnitude greater than the areal density of tips in prior field-emission devices. The electric field necessary to turn on the emission current and the current per tip in this device are both lower than in prior field-emission devices, such that it becomes possible to achieve longer operational lifetime. Moreover, notwithstanding the lower current per tip, because of the greater areal density of tips, it becomes possible to achieve greater current density averaged over the cathode area.

The thickness of the grown nitride film (equivalently, the length of the columns) could lie between about 0.5 µm and a few microns; in any event, a thickness of about 1 µm is sufficient and costs less than do greater thicknesses.

It may be possible to grow nitride emitter columns on glass or other substrate materials that cost less than silicon does. What is important in the choice of substrate material is the difference between the substrate and nitride crystalline structures. Inasmuch as the deposition process is nondestructive, an ability to grow emitter columns on a variety of materials would be advantageous in that it would facilitate the integration of field-emitter structures onto previously processed integrated circuits.

Doping seems to play an important role in the field-emission properties of the columns. The nitride in the prototype device was doped with silicon at a concentration of 5×10^{19} cm^{-3}. Other elements from groups II, IV, and VI of the periodic table could be used as alternative or additional dopants. Doping levels could range from about 10^{16} to 10^{21} cm^{-3}.

This work was done by Abdelhak Bensaoula and Igor Berishev of the University of Houston for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Lead at sammy.a.nabors@nasa.gov. MFS-32514-1

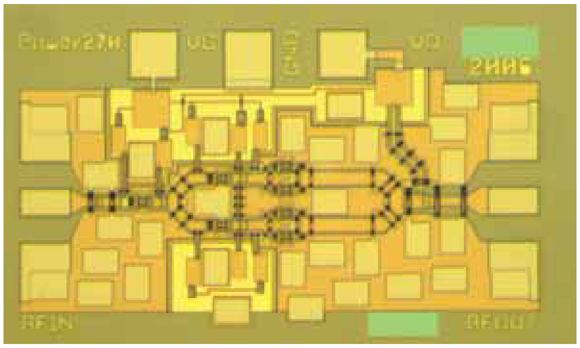
HEMT Amplifiers and Equipment for Their On-Wafer Testing

Power levels in CPW circuits can be measured without packaging.

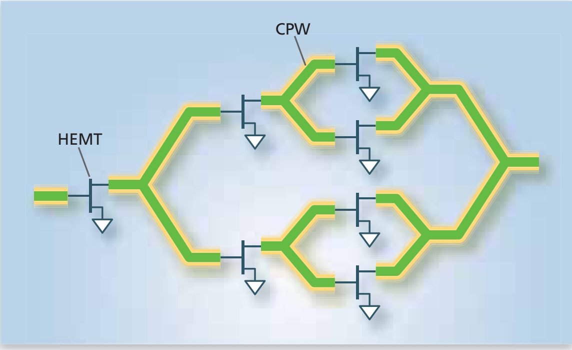
NASA's Jet Propulsion Laboratory, Pasadena, California

Power amplifiers comprising InP-based high-electron-mobility transistors (HEMTs) in coplanar-waveguide (CPW) circuits designed for operation at frequencies of hundreds of gigahertz, and a test set for on-wafer measurement of their power levels have been developed. These amplifiers utilize an advanced 35- nm HEMT monolithic microwave integrated-circuit (MMIC) technology and have potential utility as local-oscillator drivers and power sources in future submillimeter-wavelength heterodyne receivers and imaging systems. The test set can reduce development time by enabling rapid output power characterization, not only of these and similar amplifiers, but also of other coplanar-waveguide power circuits, without the necessity of packaging the circuits.

One of the amplifiers designed and tested at 330 GHz is shown in Figure 1. It is a three-stage unit containing one HEMT in the first stage, two HEMTs in the second stage, and four HEMTs in the third stage, with 1:2 CPW power splitters between the HEMT stages. The outputs of the third-stage HEMTs are coupled via a 4:1 CPW power combiner. Each HEMT is a two-finger device having an output periphery of 10 µm per finger, so that the total output periphery per HEMT is 20 µm. Hence, the total output periphery of all four third-stage HEMTs is 80 µm. Because the layout is so extremely compact that individual biasing of each stage cannot be accommodated, the gate and drain bias conductors of all seven transistors are tied together.



PHOTOMICROGRAPH



RF CIRCUIT TOPOLOGY

Figure 1. This **Three-Stage Amplifier** contains HEMTs with RF coupling via CPW structures.

Figure 2 schematically depicts the power test set as configured for characterizing this amplifier or another device at 330 GHz at different input power levels. A Gunn oscillator generates a 110-GHz signal, which is then fed via a W-band amplifier and a variable attenuator to a frequency tripler. The output of the frequency tripler is a 330-GHz power source used as the input signal for the amplifier or other device under test (DUT). A calorimeter measures the power output of the DUT. Input and output cou-

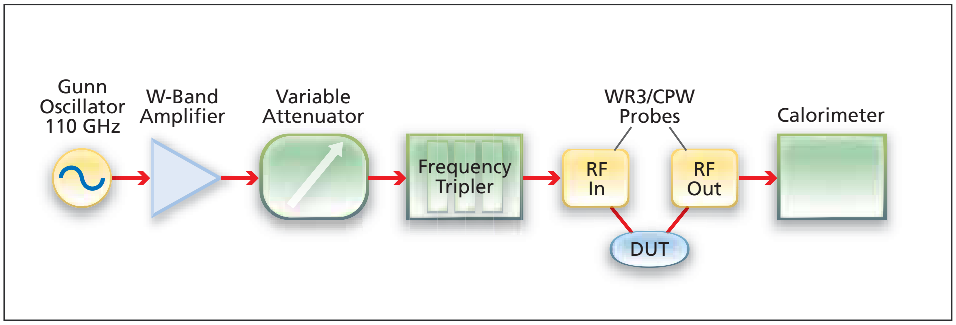


Figure 2. The Test Set feeds a 330-GHz signal to the DUT and measures the output power of the DUT. Standard sections of CPW can be substituted for the DUT for calibration measurements.

pling of the 330-GHz signals between the test set and the DUT is effected by means of commercially available waveguide probes of WR3 cross section (a standard rectangular cross section for a nominal frequency range of 220 to 325 GHz) with transitions to CPW contacts at one end. For measurement of the DUT-input 330-GHz power, the output of the frequency tripler is coupled directly via a waveguide to the calorimeter. For measurement of power levels used to correct for losses in the probes, a standard section of CPW is substituted for the DUT. In tests performed thus far, the amplifier exhibited an output power of 1.6 dB, with a maximum low power level gain of 7 dB.

This work was done by King Man Fung, Todd Gaier, Lorene Samoska, William Deal, Vesna Radisic, Xiaobing Mei, and Richard Lai of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-45022