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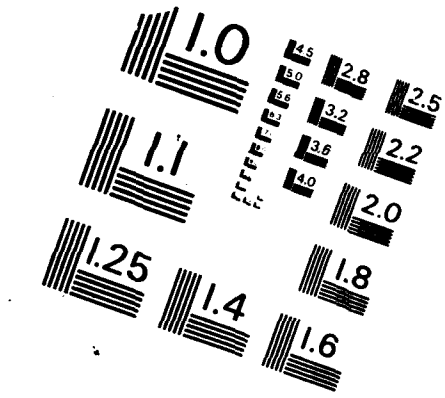

Research Progress and Forecast Report
Grant No. AFOSR-85-0193

"Investigation of a New Concept
in Semiconductor Microwave Oscillators"

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Our project centers on the fabrication and characterization of a new type of millimeter-wave semiconductor oscillator, the so-called "Contiguous-Domain" Transferred-Electron Oscillator. To date, the only operational information we have about this device has been derived from computer simulation, and therefore our objective is to obtain experimental verification.

The device is interesting (and potentially important) because it operates in a fundamentally different way from any existing semiconductor oscillator device, with the result that it should be capable of very high frequency oscillation (over 100 GHz) without the requirement for sub-micron drift dimensions. In addition, the oscillations are not based on a transit-time effect, and thus the frequency can be changed during operation by simply changing the rate at which carriers are admitted into the drift channel. The structure is similar to a conventional GaAs MESFET or MODFET, except that the gate is made resistive and has two contacts, one near the source and the other near the drain. We will not describe the operation of the device in detail here, but refer the reader to the original proposal and to the enclosed article.

Work since the beginning of the funded period has centered on developing the specific fabrication procedures needed to build the MESFET version of the device. We have learned how to do the standard processing steps, including cleaning procedures, photolithography, wet chemical etching, liftoff, metal deposition, and ohmic contact formation on GaAs. A major thrust has been the work on the technology for resistive gate formation. We will summarize this work next.

The device requires a gate having a sheet resistance of greater than 10 kΩ per square, if CW operation is to be achieved. We first investigated thin metal films of Ni, Mn, and NiCr. These materials were chosen for study because of their high bulk resistivity. We deposited thin films of each of these metals, and found that none of the films were of sufficiently high sheet resistivity to allow CW operation of the device. However, for the initial devices, we have decided to use NiCr, which can provide a sheet resistivity in the range of 100 to 500Ω per square and is stable under heat

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treatment. By using NiCr, we will be restricted to pulsed operation for the initial devices. The thin film work was quite detailed, and included a study of both optical and electrical properties of the films as a function of thickness down to the regime of discontinuity. The work was performed by Ming Fang, and has constituted his MS thesis. For future devices, we have determined that our requirements can be met by using CERMET technology. CERMETs are formed by co-sputtering a ceramic and a metal, and are capable of yielding sheet resistivities above 100 kΩ per square for even relatively thick films, say 4000 Å. We have ordered a Cr/SiO target of the appropriate composition, and plan to begin making films as soon as the target arrives.

Another essential piece of processing technology is the formation of SiN or SiO_2 films on GaAs at low temperatures. We will use a thin insulating layer between the resistive gate and the GaAs in the MESFET version of the device. This layer is not used to confine carriers, since the carriers are contained in the buried potential well in the MESFET channel away from the surface. Rather, the insulator is desirable because it increases the depth of the potential well in the channel, thus allowing us to operate in the low gigahertz range for the initial devices, and because it reduces the gate-to-drain overlap capacitance. The SiN films can also be used as cap layers for activation of ion-implants in GaAs. We have installed and calibrated a machine for plasma-assisted chemical vapor deposition (CVD) of either SiN or SiO_2 on GaAs at low substrate temperatures. The process for deposition of SiN has been perfected, and films of breakdown strength above 7×10^7 V/cm are reproducibly obtained, with resistivities above 1×10^{12} Ω-cm. The machine is now being configured for SiO_2 deposition, so that either insulator or double layers of the two insulators can be deposited. This work is being done by Robert Beaty, who is fabricating the MESFET version as his Ph.D. research.

A third crucial area is ion implantation into GaAs. We plan to use ion implantation to form the N-type channel layer in an undoped semi-insulating substrate, and also to form the source and drain regions. We are presently completing evaluations of trial implants into test wafers. The biggest challenge here is the activation procedure. We are pursuing two procedures in parallel: short radiant annealing (10 sec to one minute at 900 °C) using proximity capping, and longer thermal annealing using a SiN/SiO_2 cap layer. The proximity capping is being studied by John Kleine, a new MS student, and the capped annealing will be performed by Robert Beaty. To date, we have achieved 20-40% activation of the channel implant using proximity capping and radiant annealing, with no apparent surface degradation. We believe we can achieve 60-80% activation of these doses by optimizing the thermal pulse. We hope to avoid having to go to capped annealing, if possible.

Once the above fabrication procedures are under control, we will begin fabricating the prototype devices. The test devices have been designed, and we have already made

photomasks using our Cambridge electron beam lithography tool. We plan to dice the completed devices and mount them on 50 Ω ceramic strip lines which we have obtained from AT&T Bell Laboratories. The devices will be characterized using a spectrum analyzer and, if the frequency is low enough (below about 10 GHz), by direct observation on a sampling oscilloscope. Our weakest area in the characterization effort is the lack of a really high performance spectrum analyzer. Our analyzer is capable of only about 18 GHz performance, and will be of little use if the device oscillates at the higher frequencies predicted by the computer analysis.

I should mention that we are still collaborating with Magnavox in building test devices using the Tektronix facility in Oregon. Magnavox has committed internal funds to fabricate test devices there, and we view this as a welcome backup to our efforts here at Purdue. At the present time, Magnavox is completing discussions with Tektronix on the detailed processing schedule to be used -- their design will differ from ours in the choice of channel thickness and dopant level, but should yield comparable performance.

Turning to the theoretical work, we have found that the frequency is governed by an extremely simple relationship involving the average electron density in the channel (n) and the separation between the channel and the resistive gate (d). Thus, frequency is given approximately by $f \simeq 5.19 \times 10^{17} / (nd)$. By minimizing either n or d, we increase the oscillation frequency. During operation, we can modulate the frequency by controlling the average electron density n in the channel. This is easily accomplished by controlling the gate-to-source voltage. The theoretical maximum frequency is limited by the rule that $nd > \epsilon D / (q \mu)$, as is discussed in the enclosed paper. Thus, a maximum frequency of about 200 GHz is predicted. However, very recent computer simulations have revealed that for $d < 500$ Å, the linear frequency relationship fails, and frequencies well above 200 GHz may be obtained. This regime of very small d is not well understood as this time, but clearly some very interesting behavior is occurring there.

Finally, let me note that we have presented papers at two conferences this summer: the 1985 IEEE International Microwave Symposium in St. Louis, and the IEEE Device Research Conference in Boulder, both in June. Both presentations were greeted with a great deal of interest and enthusiasm, and we have learned that two or three research groups in this country and abroad are planning to build experimental devices to test our predictions. While this gives us some concern, we feel that we have a substantial head start, and we are determined to be the first to build and test real devices.

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