Gallium Arsenide-Based Readout Electronics

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The readout of detector arrays requires the monolithic or hybrid integration of a integrate circuit multiplexer with the detector array. In most LWIR and VLWIR applications, a hybrid approach is used. For example, the detector array may be built from HgCdTe and the readout integrated circuit may be silicon CMOS [1]. The two integrated circuits are mated through a bump-bonding process in which each detector element has its own metallized interconnect (e.g. indium bump) to a corresponding silicon multiplexer unit cell. The multiplexer unit cell may contain an integrating capacitor and other circuitry for amplification and detector biasing as well as for the unit cell readout selection. The vast majority of integrated circuits for this purpose (and for the majority of most other purposes, as well) have been made of silicon. In this paper, the use of GaAs-based integrated circuits instead of silicon CMOS ICs is explored.

The major reasons for considering GaAs for readout electronics applications, in accordance with "Woodall's Rule" [2] are as follows: First, GaAs-based devices are less susceptible to carrier freeze-out, so we expect GaAs readouts to produce less noise than silicon readouts at very low temperatures (e.g. 2-4K). The use of high-purity undoped layers is expected to enable operation to temperatures below 0.1K. Specialized GaAs-based devices have already been operated at temperatures as low as 85 mK [3]. Also, the use of lattice-matched dielectric layers such as AlGaAs rather than SiO_2 is expected to reduce interface trap effects, including surface 1/f noise. Second, GaAs-based structures are less susceptible to radiation and hot-carrier damage than are MOS-based structures. This should result in increased reliability, especially in space-borne applications. Third, the lattice thermal expansion coefficient of GaAs is better matched to LWIR materials such as HgCdTe than is silicon, increasing thermal cycling reliability for large hybrid arrays. Fourth, GaAs is the base material for new, emerging quantum-well internal photoemission (QWIP) detectors, making GaAs naturally suited for monolithic integration of the GaAs readout electronics with the detectors.

However, GaAs fabrication technology is not as mature as that for silicon, which has been driven by the enormous commercial resources of the computer, defense, and consumer electronics industries. Silicon foundries (such as MOSIS) exist which will fabricate small numbers of silicon integrated circuits for research from mask to packaging. By contrast, as mentioned above, GaAs has only gained a foothold where it enables an application that is impossible to do with silicon. Principal among these has been the construction of optical emitters such as LEDs and lasers, since efficient electroluminescence in silicon is prohibited by its indirect bandgap. GaAs has also been widely used area in high frequency analog circuits such as monolithic microwave integrated circuits (MMICs). GaAs has also been used for some very high speed digital applications. For example, Cray Corporation has announced that it will base its next generation of supercomputers on GaAs technology. Other applications, which have so far been experimental, have included devices which rely on quantum confinement effects, as well as devices that operate at cryogenic temperatures.

Presently, GaAs readout technology can draw from several types of existing devices. These include the GaAs MESFET, which is a depletion mode device that uses a Schottky barrier as the gate. Another popular technology is the High Electron Mobility Transistor (HEMT) which uses a doped and depleted AlGaAs dielectric layer over a GaAs or InGaAs channel to create a MOS-like structure. A third structure is a variation of the HEMT in which the AlGaAs layer is undoped, allowing CMOS-like applications with suitable source and drain implants. This device, named the Complementary Heterojunction Field-Effect Transistor (CHFET) has been pioneered by Honeywell [4]. Most of the devices now in existence have been optimized for very high speed applications. For example, S. Maranowski *et. al.* have recently demostrated an InGaAs MESFET with an f_T greater than 40 GHz [5], and L.D. Nguyen *et. al.* at Hughes have fabricated a HEMT with a 650 Å self-aligned gate that had a cut off frequency above 300 GHz [6]. These could easily be adapted, however, to readout electronics applications. Other devices such as GaAs JFETs and GaAs CCD technology [7] could also be used.

Research on GaAs based readout electronics is presently underway at several institutions including Hughes, Rockwell, Aerojet, Honeywell and the Jet Propulsion Laboratory. Hughes has developed HgCdTe/GaAs hybrid arrays based on a self-aligned-gate MESFET that had could withstand 1000 thermal cycles and 100 Mrads of radiation (see Fig. 1). The wafer level yield of a capacitive transimpedance amplifier was 75%. Aerojet has developed a 60x24 GaAs analog readout array, also based on MESFET technology. This activity has been centered at the 80K and higher temperature ranges.

At the Jet Propulsion Laboratory, we have been investigating the properties at very low temperatures (4-10K) of the GaAs CHFET developed by Honeywell.
The structure is shown in Fig. 2. We have completed a study of the gate leakage current and are presently investigating the noise properties at cryogenic temperatures. A complete characterization will be reported soon [8]. The transistor curves, gate current with temperature as a parameter, and the noise at subthreshold

drain currents are shown in Figs. 3, 4, and 5, respectively. We also have designed some small (8x1) multiplexer circuits, based on the CHFET technology, which are presently being fabricated at Honeywell. The unit cell and common circuitry of one such multiplexer is shown in Fig. 6.

For immediate the future it appears GaAs technology will be limited to those applications for which silicon does not work well. The number of these applications can be expected to grow, however. One will involve readout applications at steadily decreasing temperatures; for example, readout electronics capable of hybrid integration with micro-bolometers that operate below 0.1K are already being planned. Other applications involve operation in high radiation environments, and those using optical interconnects. Unless fundamental break-throughs in silicon technology occur, the electronics for these applications can be expected to be GaAs-based.

References

[1] See, for example: P.R. Norton, "Infrared Image Sensors," Opt. Eng **30** (11) pp 1649-1663 (1991).

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[7] J.I.Song, D.V. Rossi, E.R. Fossum, "GaAs CCD Readout for Engineered Bandgap Detectors," Proc. SPIE **1308** pp 254-260 (1990).

[8] To be presented in the Proceedings of the SPIE April 1992.

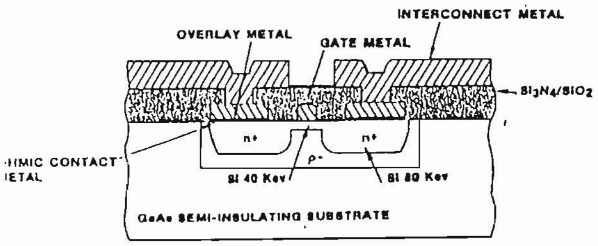

Fig. 1) The Self-Aligned Gate FET (after N. Doudoumoupoulos, Hughes Aircraft Company, used with permission).

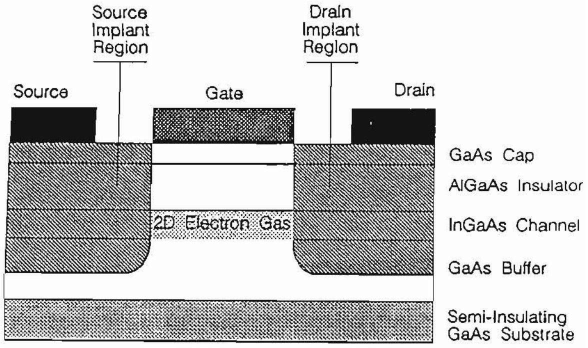

Fig. 2) The Complementary Heterojunction Field Effect Transistor (CHFET).

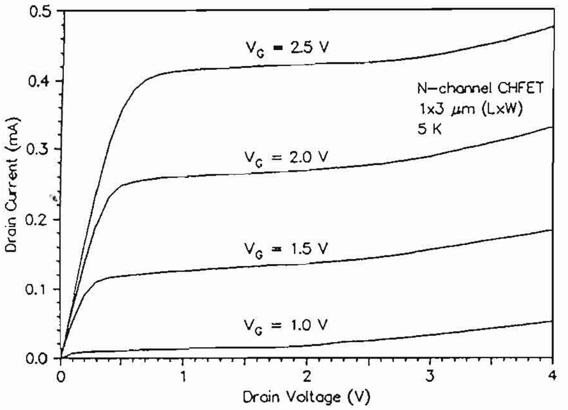

Fig. 3) The transistor curves of the CHFET.

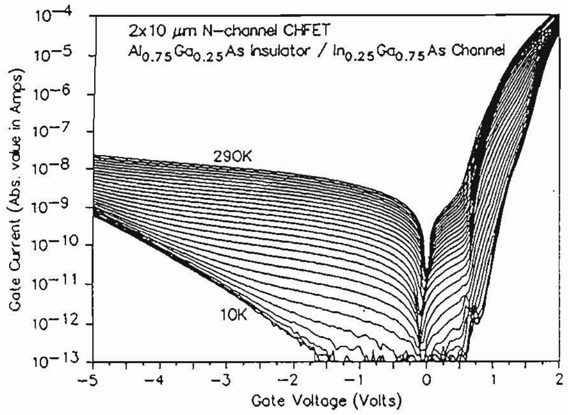

Fig. 4) The gate current in a CHFET with temperature as a parameter.

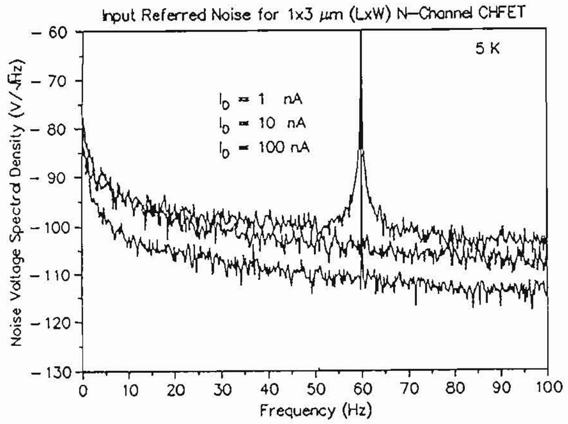

Fig. 5) The input referred noise in a 1x3 μm (Lxw) CHFET at subthreshold drain currents.

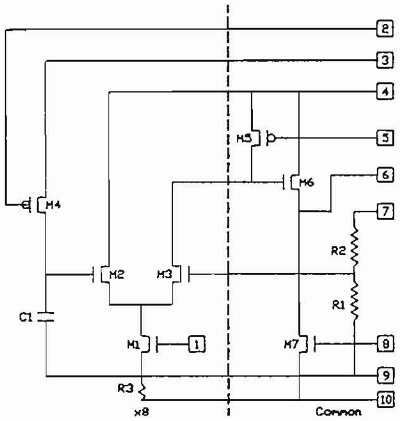

Fig. 6) The Switched Follower 8x1 multiplexer based on GaAs CHFET technology.