high average chip current density capability of 1000 A/cm^2 approaching present microwave power bipolar chips, 2) a relatively high per-unit transconductance of 20 μmho/μm, 3) a high peak current capability of 200 μA/μm, exceeding presently available microwave bipolar designs by a factor of 2, and 4) an inherent negative temperature coefficient of ν_{sat} in the channel, obviating the need for additional second-breakdown limiting ballasting resistors.

Preliminary RF results include 1.2-W pulsed saturated power output at 0.7 GHz, and a CW small-signal device gain of 10 dB at 1.0 GHz.

Parasitic source resistance is at present limiting the device $f_{\max}$ to 2.5 GHz. Calculations have shown that elimination of this parasitic effect should result in an $f_{\max}$ of 4 to 6 GHz for present devices. This is significant considering the relatively coarse 8-μm design rules used in fabricating these structures. Projected power-impedance performance of this 8-μm design rule MOS device is 2.5 W CW class A at 4 GHz with an input impedance of about 3–10 Ω. The high input impedance of this MOS transistor in conjunction with the *constant* input and output capacitances inherent in an epitaxial vertical MOS device should lead to a large-bandwidth, ultralinear class A power transistor suitable for power amplification and signal processing at gigahertz rates with a minimum of amplitude and phase distortion. In addition, tighter photoresist design rules and thinner epitaxial layers are expected to eventually push power–performance up through *X* band.

Session II

Charge-Coupled Devices

II-1 A Comparison of Two Types of Buried-Channel Charge-Coupled Devices—R. W. Brodersen and A. F. Tasch, Jr., Texas Instruments Inc., Dallas, Tex. 75222.

The fabrication of buried-channel charge-coupled devices (BCCCD) has been performed using two different techniques. One method is to use ion implantation to change the impurity type of the surface layer in order to move the signal charge away from the silicon–silicon dioxide interface.[1] Another method is to use material which has an epitaxial layer of opposite impurity type from the substrate that forms the buried-channel layer.[2] A comparison of the operation of these two devices is given. Both types of BCCCD's were fabricated using the same 150-stage four-phase-shift register, and transfer efficiencies of these devices ranged from 0.9999 to 0.99999. A model will be presented to interpret these variations in transfer efficiency in terms of an effective bulk state density.

The differences in the distribution of the doping impurities in the buried-channel layer which are introduced by the aforementioned two techniques will be analyzed for the effect on transfer efficiency, noise, high-frequency operation, and dynamic range. The need for a small bias charge (slim zero) to obtain maximum performance will be shown to be affected by these differences in impurity distribution.

In making these comparisons, the concept of an effective threshold will be presented which is very useful for predicting all the operating voltages needed for a BCCCD. It will be shown that the important parameters that determine this effective threshold are closely controlled in an ion-implanted BCCCD, whereas specific values are more difficult to achieve in an epitaxial BCCCD.

[1] R. H. Walden *et al.*, "The buried channel charge coupled device," *Bell Syst. Tech. J.*, Sept. 1972.

[2] M. Esser, "Peristaltic charge-coupled device: A new type of charge transfer device," *Electron. Lett.*, vol. 8, Dec. 14, 1972.

II-3 The Effects of Bulk Traps on the Performance of Bulk Channel Charge-Coupled Devices—A. M. Mohsen and M. F. Tompsett, Bell Laboratories, Murray Hill, N. J. 07974.

The effects of trapping of the signal charge in bulk traps, which exist at discrete energy levels in the buried channel, on the transfer efficiency and transfer noise in bulk channel charge-coupled devices (BCCD's) are presented. The effects of the charge packet size and frequency on the transfer efficiency and transfer noise in BCCD's are calculated and compared with experimental results, and the distribution and density of bulk states are measured. A new technique of measuring the density and distribution of the bulk traps in the buried channel is presented. The measured low transfer inefficiency of 10^{-4} per transfer with no intentionally introduced background charge and low transfer noise are shown to be due to a low bulk state density of $2 \times 10^{11}/\text{cm}^3$. A detailed comparison of estimated noise in both surface and bulk channel versions of an image sensor and analog delay lines show that BCCD's are very attractive for low light level imaging but not as attractive for analog signal processing applications.

II-5 A Two-Phase Germanium CCD—D. K. Schroder, Westinghouse Research Laboratories, Pittsburgh, Pa. 15235.

The present approach to infrared imaging using charge-coupled devices (CCD's) is the combination IR detector/Si CCD readout.[1] The Si CCD is used for multiplexing and to perform the delay-and-add operation. This approach can be simplified by using an IR CCD directly. In addition to low power dissipation, low noise, and focal-plane signal processing, an IR CCD should be easier to fabricate with no external interconnects making for a simpler more compact device.

As a first step in this direction, we have developed a CCD in Ge. It operates as an imager over the 0.6-μm to 1.8-μm wavelength band, making it useful for the night-glow spectrum and the 1.06-μm laser line. There are also atmospheric transmission windows in this wavelength band.

The CCD is a ten-stage two-phase device, in which directionality is achieved by a two-level oxide with self-aligned angle-evaporated Al electrodes.[2] This technique allows the gap between electrodes to be reduced to 0.5 μm. Ion implantation is used for both the channel stop surrounding the active device area (implanted phosphorus) and for the input and output diodes (implanted boron). The device, with a chemically vapor deposited SiO_2 as the insulator, was operated over a temperature range of 100–265 K and 10 kHz to 400 kHz. At 200 K and 100 kHz the transfer efficiency was 97.5 percent. However, surface state measurements on MOS capacitors indicate that values somewhat above 99 percent are possible. Dark storage times of 1 s (sufficient for area imagers) have been measured at 225 K, a temperature within thermoelectric cooling capability.

[1] D. M. Erb and K. Nummedal, "Buried channel CCD's for IR applications," in *Proc. CCD Applications Conf.*, San Diego, Calif., 1973, pp. 157–167.

[2] I. M. Baker and J. D. E. Beynon, "CCD's with submicron electrode separations," *Electron. Lett.*, vol. 9, pp. 48–49, Feb. 8, 1973.

II-6 An Infrared-Sensitive Charge-Coupled Imager[1]—E. S. Kohn, RCA Laboratories, Princeton, N. J. 08540.

A charge-coupled imager sensitive to infrared light as far out as 3 μm has been fabricated and operated. It consists of a linear array of 64 Pd:p-Si Schottky barrier detectors adjacent to a three-phase charge-coupled shift register. We believe this to be the first time Schottky barrier detectors have been used with a charge-coupled device (CCD). The design has a single level of metallization with gaps. A single transmission gate, when pulsed on, couples each detector to its associated shift register gate, thereby setting each barrier to a reverse bias determined by the potential applied to the transmission gate. Incident infrared light discharges the individual detectors during the detector exposure time. The charges transferred into the CCD shift register the next time the transmission gate is pulsed are transferred out sequentially by the charge-coupled shift register to produce the video signal. The output is obtained from a floating diffusion connected to an on-chip MOSFET.

The shift register had transfer losses as low as 5×10^{-4} per transfer as measured with an electrical input. Visible images could be sensed directly by illumination of the shift register through the gaps as well as through the unthinned substrate. Infrared images ($1.1\ \mu\text{m} < \lambda < 3.0\ \mu\text{m}$) were sensed by the Schottky barrier detectors illuminated through the (transparent) substrate. The two imaging modes could be easily distinguished by their spectral sensitivities as well as by their response to changes in integration

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