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B-3-1 CHARACTERISTICS OF THE INDIUM- AND GALLIUM-DOPED SILICON** INFRARED SENSING MOSFET's (IRFET's)

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ABSTRACT

The extrinsic silicon infrared sensing MOSFET (IRFET)[1,2,3,4,5] is an integrated circuit element which has been designed for infrared imaging applications employing large scale integrated arrays, in the near, middle, and far infrared wavelength regions. Detailed results have been previously published on the operation of the gold-doped devices in the near infrared wavelength region[3].

This paper specifically addresses the characterization of the indium-doped and gallium-doped infrared sensing MOSFET in the middle, 3 to 5 micrometer, and far, 8 to 14 micrometer, wavelength regions respectively. The devices are based on standard n-channel silicon MOSFET technology except the substrate is doped with indium or gallium in addition to the boron in the normal p-type substrate.

The device operates on an indirect observation of impurity charge states in the surface depletion region of the MOSFET device structure. Modulation of the charge state of the impurity center, either indium or gallium, in the space charge region causes a change in the MOSFET threshold voltage and modulation of its conductivity. The device is an integrating detector and must be periodically reset by turning the MOSFET off by accumulating the surface, and the device works much like a static or D.C. read only memory element. Low temperature operation, 20 to 50°K, is required to avoid thermal emission and ionization of the impurity centers. At low temperatures in a depletion region then, only optical emission of photoionization is possible as a means for the initially neutral acceptor impurity centers to change charge state. This photoionization is then the basis for device operation.

In operation the device is first reset by accumulating the surface and filling all the impurity centers with holes and leaving them in the neutral charge state. The MOSFET is then operated in the on conduction state by applying an inversion voltage to the gate. This inversion voltage and any back-gate or substrate bias forms a surface depletion region. If the neutral acceptor centers subsequently change charge states from neutral to negative the number of electrons or amount of negative charge in the inversion layer or channel must decrease, resulting in a lower conductivity.

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The IRFET has some very unique characteristics as an infrared detector, it is an integrating detector with an inherent memory capability, the conductivity can be measured on a static or D.C. basis, it is a negative photoconductivity element, can have a very high gain due to the inherent active nature of the transistor action, and is based upon a standard integrated circuit device structure, the MOSFET.

The results presented will describe the fabrication, operation and characterization of indium- and gallium-doped devices. Not only will operation of the device be demonstrated but it will also be shown that the MOSFET device structure possess some unique abilities in the characterization of impurity centers in silicon. Specifically, measurements have been made of the thermal emission rates, thermal ionization energies, field-enhanced thermal emission by the Poole-Frenkel effect of the gallium center, and photoionization cross sections.

It will be shown that operation of the MOSFET as an infrared detector can be described on the basis of a fairly simple modification of the equations describing normal MOSFET operation. Responsivities of 100 microamps/microwatt are easily achieved. Under background or shot noise limited operation it will be further shown that the maximum attainable signal to noise ratio depends only on the area of the detector and surface charge storage density. Since in the case of the MOSFET (IRFET) detector the responsivity increases as the area decreases much higher responsivities, but lower signal to noise ratios, are possible by using smaller area devices.

As a consequence of the unique characteristics the infrared sensing MOSFET (IRFET) might be particularly useful in some large scale integrated infrared imaging array applications[5].

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