Hydrogenation of ZnS passivation on narrow-band gap HgCdTe

J. K. White and C. A. Musca
Department of Electrical and Electronic Engineering, The University of Western Australia, Nedlands, WA 6907, Australia

H. C. Lee
Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Kusong-Dong, Yusong-Gu, Taejon, Korea

L. Faroone
Department of Electrical and Electronic Engineering, The University of Western Australia, Nedlands, WA 6907, Australia

(Received 1 November 1999; accepted for publication 2 March 2000)

Due to the narrow band gap of HgCdTe required for infrared photodetectors, the device performance is readily influenced by surface effects. This letter examines the effect that hydrogenation has on the quality of industry-standard ZnS passivating films. The hydrogenation is achieved by exposing the samples to a H₂/CH₄ plasma that is present during a reactive ion etching process. The results show a marked improvement of the passivant/substrate interface for hydrogenated devices with a reduction of the average fixed interface charge density to 3.5 × 10¹⁰ cm⁻², accompanied by a sixfold decrease in the standard deviation. The advantage of this method of hydrogenation is that it is integrated into the reactive ion etch processing for mesa formation or p-type to n-type conversion in photoconductive or photovoltaic device fabrication, respectively. With the improvement of the ZnS passivation with hydrogenation, this method may alleviate the need for complex epitaxial passivation processing. © 2000 American Institute of Physics.

Using current fabrication technology the performance of HgCdTe infrared detectors is limited by surface effects. With a band gap ranging from 0.1 eV [long-wavelength infrared (LWIR)] to 0.25 eV [midwavelength infrared (MWIR)], photodetector characteristics are strongly influenced by the quality of the surface passivation. Ideally, surface passivation should perform a number of functions; provide optimal bandbending at the surface (none for photodiodes and slight accumulation for photoconductors), a low density of fast and slow interface states, good adhesion and low stress, thermal and chemical stability, and good electrical insulation. A number of techniques for passivating HgCdTe have been investigated, and presently epitaxially grown CdTe passivation produces the highest-quality photodiodes. Using ZnS/CdTe passivation, fixed-charge densities of (5 ± 2) × 10¹⁰ cm⁻² and a small hysteresis (0.1V) have been reported by Bahir et al. At this time, commercial production of LWIR photodiode arrays makes use of CdTe passivation, while MWIR photodiodes with their larger band gap are capped using the simpler process of ZnS/Si₃N₄ passivation. The disadvantage of the CdTe passivation process is the added complexity of epitaxial growth and the lack of a selective etch for CdTe/HgCdTe.

At the passivation HgCdTe interface, trapping sites and fixed insulator charge degrade device performance. Interface traps increase carrier generation which in turn increases the dark current. Fixed insulator charge can accumulate, deplete, or invert the surface. In photodiodes this will bend the bands at the surface away from flatband, thus widening or narrowing the space-charge region. Increased space-charge width allows a greater area for dark current generation. Narrowing of the space-charge region increases tunneling current across the junction. Ideally for photodiodes, flatband conditions should prevail at the surface in order to minimize leakage currents. Photoconductors optimally require a very slightly accumulated surface in order to separate the photo-generated carriers from the surface traps. In silicon processing, interface and fixed-oxide charges are controlled by crystal orientation and postoxide growth annealing in a hydrogen atmosphere. Using various mixes of gases, hydrogen ions are introduced into the SiO₂ where they are believed to diffuse to the interface and quench interface traps and oxide

FIG. 1. Normalized C–V for nonhydrogenated MIS capacitors.

*Electronic mail: johnw@ee.uwa.edu.au
fixed charge. With regards to HgCdTe, applying the hydrogenation method for improving the passivation has shown promising results. Kim et al. have reported an order of magnitude improvement in the $R_{\mu}A$ of LWIR photodiodes, after being subjected to hydrogenation. This letter examines the effect on the passivation/HgCdTe interface of reactive ion etching induced hydrogenation.

One of the most attractive features of potential fabrication processes is simplicity. Reaction ion etching is used in etch induced hydrogenation. effect on the passivation/HgCdTe interface of reactive ion etching as a CdTe epitaxial cap, however, when the ZnS passivation alone does not produce an interface of the same quality made between metal–insulator–semiconductor (MIS) capacitors fabricated on hydrogenated and nonhydrogenated ZnS passivation. The RIE process used in this work is thought to provide a similar environment to that present during the hydrogenation of silicon.

In order to examine the effect of RIE hydrogenation on a passivating ZnS film, a HgCdTe wafer passivated with ZnS was cut in half with one side undergoing hydrogenation and MIS capacitors then patterned on both halves. In detail, a wafer (1 cm diam) of bulk $x=0.3$ vacancy-doped $p$-type ($N_v=1 \times 10^{16}$ cm$^{-3}$) HgCdTe was cleaned with solvent, HCl, and finally, a Br/methanol solution. 3000 Å of ZnS was thermally deposited at 0.1 Å/s with the wafer held at 50 °C. With a protective coating of photoresist the wafer was then patterned with Cr/Au using a lift-off process. On the resulting MIS capacitors (area = 1 cm$^2$), high-frequency $C-V$ measurements were performed behind a cold shield at 77 K using a HP4180A 1 MHz $C-V$ profiler. The gate electrode was swept from 8 to $-8$ V and back to 8 V with step and hold times of 0.01 and 100 s, respectively.

The resulting $C-V$ curves (Figs. 1 and 2) showed a significant (94% confidence) improvement (decrease) in the fixed-charge density for the hydrogenated capacitors. The sum of fast interface states (at flatband) and fixed-charge density shifted from an average of $N_f=1.1 \times 10^{11}$ cm$^{-2}$ (no hydrogenation) to $3.5 \times 10^{10}$ cm$^{-2}$ (with hydrogenation). The standard deviation also decreased from $8.2 \times 10^{10}$ to $1.3 \times 10^{10}$ cm$^{-2}$ for the nonhydrogenated and hydrogenated ZnS, respectively. Average flatband voltages changed by only 0.1 V towards depletion, however, the standard deviation of the flatband voltage decreased by a factor of 5 for the hydrogenated capacitors. Significant hysteresis (0.9 V) was observed in all of the $C-V$ curves. The distributions of hysteresis at $V_{FB}$ for hydrogenated and nonhydrogenated devices was not statistically distinguishable, suggesting that the slow interface charge density ($N_a$) was unchanged (Fig 3). The experimental results are summarized in Table I. These results indicate that in terms of fixed-charge density and fast interface states, the quality of the hydrogenated ZnS passivation is in line with that of epitaxially grown CdTe, and that the

![FIG. 3. Normalized $C-V$ for hydrogenated and nonhydrogenated capacitors normalized against flatband voltage and maximum capacitance.](Image)

### TABLE I. Summary of experimental results.

<table>
<thead>
<tr>
<th></th>
<th>$N_f$ (No./cm$^2$)</th>
<th>$V_{FB}$ (V)</th>
<th>Hysteresis at FB (V)</th>
<th>Insulator capacitance (nF/cm$^2$)</th>
<th>ZnS Thickness (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No hydrogenation average</td>
<td>$1.1 \times 10^{11}$</td>
<td>0.1</td>
<td>0.9</td>
<td>23.5</td>
<td>2800</td>
</tr>
<tr>
<td>With hydrogenation average</td>
<td>$3.5 \times 10^{10}$</td>
<td>0.2</td>
<td>0.9</td>
<td>24.7</td>
<td>2670</td>
</tr>
<tr>
<td>No hydrogenation Std. Dev.</td>
<td>$8.2 \times 10^{10}$</td>
<td>1.0</td>
<td>0.06</td>
<td>0.02</td>
<td>23</td>
</tr>
<tr>
<td>With hydrogenation Std. Dev.</td>
<td>$1.3 \times 10^{10}$</td>
<td>0.2</td>
<td>0.06</td>
<td>0.04</td>
<td>38</td>
</tr>
</tbody>
</table>
uniformity of hydrogenated ZnS is superior to nonhydrogenated layers. The large and nonsymmetrical hysteresis seen in both hydrogenated and nonhydrogenated samples may be due to the use of bulk rather than epitaxially grown HgCdTe. Further experiments are needed to evaluate the effect of hydrogenation on slow interface states.

Hydrogenation of a ZnS-passivating film on HgCdTe improves the passivation/HgCdTe interface quality. The devices fabricated for this experiment showed a reduction in fixed-charge density from $1.0 \times 10^{11}$ to $3.5 \times 10^{10}$ cm$^{-2}$ and a six times reduction in the standard deviation. This will improve both the performance and uniformity of HgCdTe devices. Interestingly, there was no change in the density of slow interface traps. The hydrogenation process can be integrated with mesa formation or type-conversion steps using a reactive ion etcher. Given the low fixed-charge density, it may be possible to replace epitaxially grown passivation with hydrogenated ZnS passivation, thus providing a significant reduction in device processing.

The authors would like to thank S. H. Bae and Young Ho Kim of the Korea Advanced Institute of Science and Technology for their discussions and technical assistance and the Australian Research Council (ARC) for financial support.