THE OXIDE BARRIER VARACTOR

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The heterostructure barrier varactor [1] consists of a layer-cake of alternating low and high band-gap semiconductor materials, for example GaAs and AlGaAs. As bias is applied in either direction across the layers, the electrons in the moderately doped low band-gap layers form a two-dimensional electron gas against the conduction band discontinuity at the heterojunction. Thus, most of each low band-gap layer becomes depleted, forming capacitance modulation layers while the high band-gap materials are barrier layers to prevent conduction current. Since these devices have a symmetric capacitance-voltage characteristic centered at zero-bias, they cannot generate even order harmonics and don t require a bias circuit or even harmonic idler circuits. Thus, they are ideal frequency triplers and quintuplers. Also, since any number of barriers can be epitaxially stacked, the power handling of the device can be made quite large.

The primary problem with HBVs is that the conduction band discontinuity between most suitable semiconductor materials is not large enough to prevent a significant thermionic emission leakage current. This current can greatly reduce the useful capacitance modulation of the HBV. In terms of circuit design, the devices have a very high-Q, which makes it difficult to achieve broadband performance without several mechanical tuners. Although it has recently been shown that the InGaAs/InAlAs system yields much improved characteristics, and excellent results to 250 GHz have been achieved [2], the very limited fixed-tuned bandwidth of HBV multipliers remains a serious drawback that will prevent this technology from being useful in most applications.

Our new device is identical to the HBV except that an oxide replaces the semiconductor barrier layers [3]. The expected result is a much higher barrier height that greatly reduces leakage current. This allows the properties of the modulation layers to be optimized to achieve maximum capacitance modulation without regard to the barrier materials. Also, we can implement this process with GaAs rather than InGaAs, so that avalanche breakdown is not as prevalent. A review of the literature shows that many groups have attempted to find a suitable oxide material on GaAs. In particular, one group has succeeded in laterally oxidizing AlGaAs layers in a mesa structure to form Al_2O_3 layers that serve as waveguiding regions for optical devices [4]. Their work was the original basis for our proposed Oxide Barrier Varactor.

To date, we have fabricated several test batches of whisker contacted OBV devices. Since oxidation of the AlGaAs is the last process step, we are able to measure the parameters of the HBV diode before the layers are oxidized to form the OBV device structure. Initial tests have shown that the turn-on voltage (defined here as 1 uA) was increased by an order of magnitude after oxidation. However, the resulting OBV device showed no capacitance modulation.

It is now understood that the oxidation process leaves a significant amount of metallic arsenic at the GaAs-oxide interface. This creates a large concentration of interface states that pins the Fermi level near mid-gap and causes the modulation layers to be depleted regardless of applied bias.

There are several possible ways to solve this problem. First, the oxidation process can be varied. Perhaps a different heating cycle or ambient atmosphere will allow more of the arsenic to be removed. Similarly, a new device geometry that has a greater periphery to area ratio may allow more of the Arsenic to escape. Also, other materials might eliminate the problem altogether. For example, perhaps a GaN layer can be substituted for the AlGaAs layer. However, to date no suitable solution has been demonstrated.

Summary:

The oxide barrier varactor is proposed as an adaptation to the more common heterostructure barrier varactor. Its structure is essentially the same except an oxide replaces the high-barrier semiconductor material that forms the heterostructure barrier. The result should be a drastic reduction in conduction current thereby allowing the fabrication of HBV-like devices with greatly improved performance. Although the OBV structure can be formed by lateral oxidation of AlGaAs layers, the resulting interface state density is too high. This causes the modulation layers to be depleted and destroys the capacitance modulation. Although there are many possible solutions to this problem, it remains a major challenge.

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