Mercury cadmium telluride detectors achieve high operating temperatures

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The processing of mid-wave mercury cadmium telluride IR detector arrays grown by metal organic vapor-phase epitaxy was adapted to achieve high performance at high operating temperatures.

In recent years, high-temperature operation has been strongly emphasized in the development of high-performance detectors for thermal imaging to achieve improved size, weight, power, and time to first image. These factors are particularly important for handheld and battery-powered thermal imagers, including individual weapon sights. Mercury cadmium telluride (HgCdTe) and indium antimonide (InSb), for many years the favored detector materials, have been challenged by bandgap-engineered structures such as type II superlattices and nBn bandgap-engineered, three-layer detector structures incorporating a barrier layer between the n-type layers. These structures have some theoretical advantages for higher operating temperatures. Whereas the shrinking bandgap of InSb strongly limits operation at temperatures >100K, the ability to tailor the HgCdTe bandgap at any temperature avoids this fundamental limitation. The tailoring is achieved by optimizing the alloy composition. For function at high operating temperatures in the 3–5 μm waveband, the required composition has a cadmium telluride (CdTe) mole fraction of 0.3.

We have produced mid-wave HgCdTe detectors by metal organic vapor phase epitaxy (MOVPE) for more than 10 years, for operation in the majority of applications at temperatures <100K. An early exploration of performance at high temperatures was undertaken in 2003, which led to the conclusion that excess noise was the main cause of non-ideal behavior. The high temperature performance of a standard detector from the MOVPE production line was revisited in 2011. Its median performance was observed to be dominated by shot noise on the dark current, an improvement over the 2003 result that reflected the general improvements in the technology over the intervening 8 years.

Notwithstanding those improvements, the main conclusion was that the performance of the HgCdTe photodiode technology at high temperatures is still dominated by technological rather than physical limitations. In particular, the role of recombination centers in the generation-recombination process is a key factor in determining the dark current.

We designed experiments to evaluate the sensitivity of dark current and defective pixel count to a range of process parameters, including mesa geometry. The mesa array geometry also permits a degree of optical concentration into a reduced area p-n junction towards the mesa top, with possible improvements in dark current, and this approach...
was not optimized in the 2011 work (see Figure 1). Our experiments used the multivariant array technique whereby individual arrays or wafers are divided into multiple regions, each of which receives a unique combination of process parameters. Although the performance of the various regions is broadly similar at conventional operating temperatures <100K, significant differences emerge at higher operating temperatures, revealing a strong dependence on the process variations. The defect levels of such an array are shown in the map of noise equivalent temperature difference (NETD) defects in Figure 2.

In that example, photomask dimensions are different for the equal-sized zones 1–6, and a further process split at wafer level shows a diagonal boundary between areas A and B. Taken together, these variations result in 10 different regions, with the best region 3B towards the top right-hand corner of the array exhibiting 0.3% of NETD defects.

Figure 2. Noise equivalent temperature difference (NETD) defect levels at 150K in a multivariant HgCdTe mesa array with 6 rectangular zones 1–6 and two areas, A and B.

We recorded dark current measurements for the array over the temperature range 110–180K (see Figure 3).

The median dark currents, which are different for the 10 regions, show a strong dependence on variants A and B and a moderate dependence on variants 1–6. The region of lowest dark current is the same region (3B) that exhibited the lowest defect levels. In this region, the dark current at 150K is a factor of 10 lower than in the standard production process, enabling the operating temperature to be raised by tens of degrees without loss of performance. Applying the measured median dark currents to a shot-noise limited model of NETD, the predicted NETD as a function of operating temperature is presented in Figure 4 and compared with the prediction for the standard HgCdTe process and the theoretical background limit (including f/4 radiation shield emissions).

We raised the near-background limited performance achieved at 150K by the standard process around 30K to 180K for region 3B, with the expectation of background-dominated performance to well above 200K (see Figure 4).

The multivariant array technique has proven to be a powerful tool in the investigation of the high operating temperature performance of mid-wave HgCdTe detector arrays. In an initial campaign to optimize process parameters specifically for high temperature operation, we established a set of process modifications that effectively raise the operating temperature by 30K for a given high performance level, from 150K to 180K. This program of work has also identified opportunities for further optimization of the array process that may lead to even higher operating temperatures and lower defect levels.
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References