Final Remarks

Recent efforts in the technology of infrared detectors have focused mostly on large electronically scanned focal plane arrays (FPAs). The increased sensitivity and resolution in the system complexity of FPAs offer significant advantages in military as well as civilian applications in thermal imaging, guidance, reconnaissance, surveillance, ranging and communication systems.

Figure 1 shows a plot of the thermal detectivity (300 K, 0° FOV) versus operating temperature for the most prominent detector technologies. The thermal detectivity is used here to compare the various technologies for equivalent NETD irrespective of wavelength. The thermal D^* figure of merit for photon detectors was obtained by equating the NETD of an ideal thermal detector for a given D^* to the NETD of an ideal photon detector with a given $D^*_{\lambda_p}$. The various regions show the appropriate applications including "low-cost" uncooled thermal detectors, "high-performance uncooled" for night vision enhancement and earth reconnaissance, "tactical" for most imaging uses, and "strategic" for various military-type instruments. For low-cost applications, the imagery is limited by the thermal conduction to the pixels. Photocurrent shot noise should limit the detectivity for other thermal imagers. Strategic sensors generally detect point targets, so the D^* must be as high as possible within the constraint that the cooler must not pose overriding size, weight, reliability or cost issues. High-performance near-infrared has similar performance requirements, but can only provide a minimum of cooling because cost and weight minimization is critical. The extrinsic silicon detectors offer very high sensitivity, but at very low operating temperature, which is prohibitive in most applications. The cryogenically cooled InSb and HgCdTe arrays have comparable array size and pixel yield at the MWIR spectral band. However, wavelength tunability and high quantum efficiency have made HgCdTe the preferred material. This material assures the highest possible operating temperature for a given set of operating conditions. Thus, the associated cooling and system power requirements can thus be optimally distributed. The monolithic PtSi Schottky barrier FPAs lead all other technologies with respect to array size (10^6 pixels); however, the thermal mismatch barrier in hybrid FPAs has been recently overcome by developers (InSb and HgCdTe arrays).

Historically, thermal detectors were the first detectors operated in the infrared range of electromagnetic spectrum. Since circa 1930, the development of infrared technology has been dominated by the narrow-gap semiconductor photodetectors. In comparison with photon detectors, thermal detectors have been considerably less exploited in commercial and military systems. In the last decade, however, it has been shown that extremely good imagery can be obtained from large thermal detector arrays operating uncooled at TV frame rates. The speed of thermal detectors is quite adequate for nonscanned imagers with two-dimensional detectors.

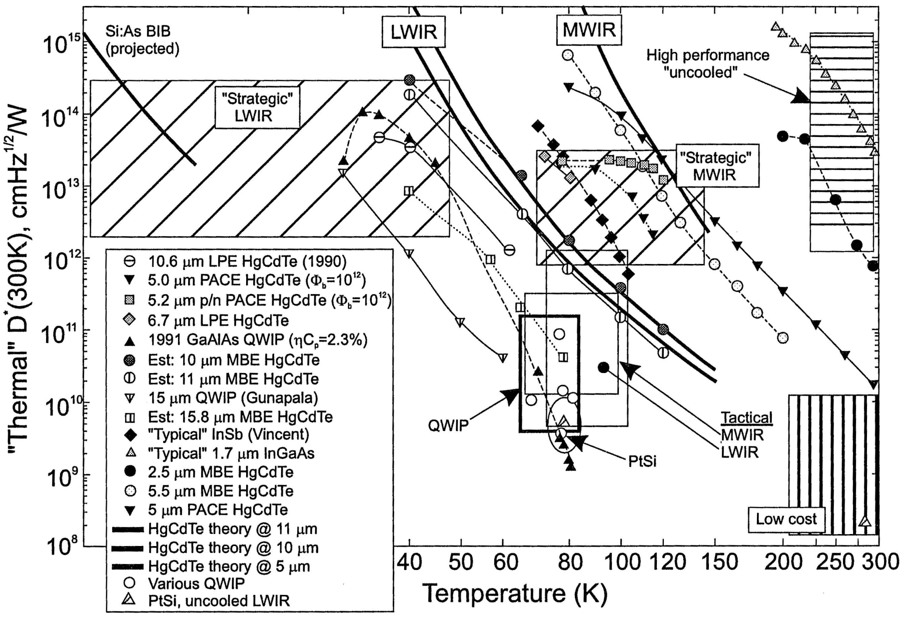

Fig. 1. Thermal D* versus operating temperature for different FPA technologies (after Ref. 1).

During the past four decades, mercury cadmium telluride (HgCdTe) has became the most important semiconductor for the middle and long wavelength (λ = 3–30 μm) infrared (IR) photodetectors. The short-wavelength region has been dominated by III–V compounds (InGaAs, InAsSb, InGaSb). From fundamental considerations, HgCdTe is the most important semiconductor alloy system for infrared detectors. There have been numerous attempts to replace HgCdTe with alternative materials. At present, several other variable-gap alloy systems are known, including closely related mercury alloys HgZnTe, HgMnTe, lead tin tellurides and selenides, InAsSb, III-VI compounds with thallium and bismuth, free-carrier detectors and low-dimensional solids.[2–5] The main motivations are the technological problems of this material. One of them is a weak Hg–Te bond, which results in bulk, surface and interface instabilities. Uniformity and yield are still issues. Nevertheless, HgCdTe remains the leading semiconductor for IR detectors. The most important reasons are

- Not one of the new materials offers fundamental advantages over HgCdTe. Detectivity of any type of infrared photodetector is proportional to $(\alpha/G)^{1/2}$ (see Section 1.3), where α is the absorption coefficient and G is the thermal generation rate. While this figure of merit of various narrow-gap semiconductors seems to be very close to that of HgCdTe, the extrinsic silicon and germanium detectors, Schottky-barrier photoemissive detectors and GaAs/AlGaAs superlattice devices have a several orders of magnitude smaller α/G ratio.
- HgCdTe exhibits extreme flexibility: it can be tailored for optimized detection at any region of IR spectrum, dual and multicolor devices can be easily constructed.

- The present development of IR photodetectors has been dominated by complex bandgap heterostructures. Among various variable-bandgap semiconductor alloys, HgCdTe is the only material covering the whole IR spectral range that has nearly the same lattice parameter (see Fig. 10.2). The difference between the lattice parameter of CdTe (E_g = 1.5eV) and $Hg_{0.8}Cd_{0.2}Te$ (E_g = 0.1 eV) is ≈ 0.2%. Replacing a small fraction of Cd with Zn, or Te with Se, can compensate the residual lattice mismatch. The independence of lattice parameter from composition is a major advantage of HgCdTe over any other materials.

In Fig. 2, plots of the calculated temperature required for background-limited (BLIP) operation in 30° FOV are shown as a function of cutoff wavelength. We can see that the operating temperature of HgCdTe detectors is higher than for other types of photon detectors. HgCdTe detectors with background limited performance operate with thermoelectric coolers in the MWIR range; instead, the LWIR detectors ($8 \leq \lambda_c \leq 12$ μm) operate at ≈ 100 K. HgCdTe photodiodes exhibit a higher operating temperature compared to extrinsic detectors, silicide Schottky barriers and quantum well infrared photodetectors (QWIPs). However, the cooling requirements for QWIPs with cutoff wavelengths below 10 μm are less stringent in comparison with extrinsic detectors and Schottky barrier devices. HgCdTe is characterised by a high optical absorption coefficient and quantum efficiency and relatively low thermal generation rate as compared to extrinsic detectors, silicide Schottky barriers and QWIPs.

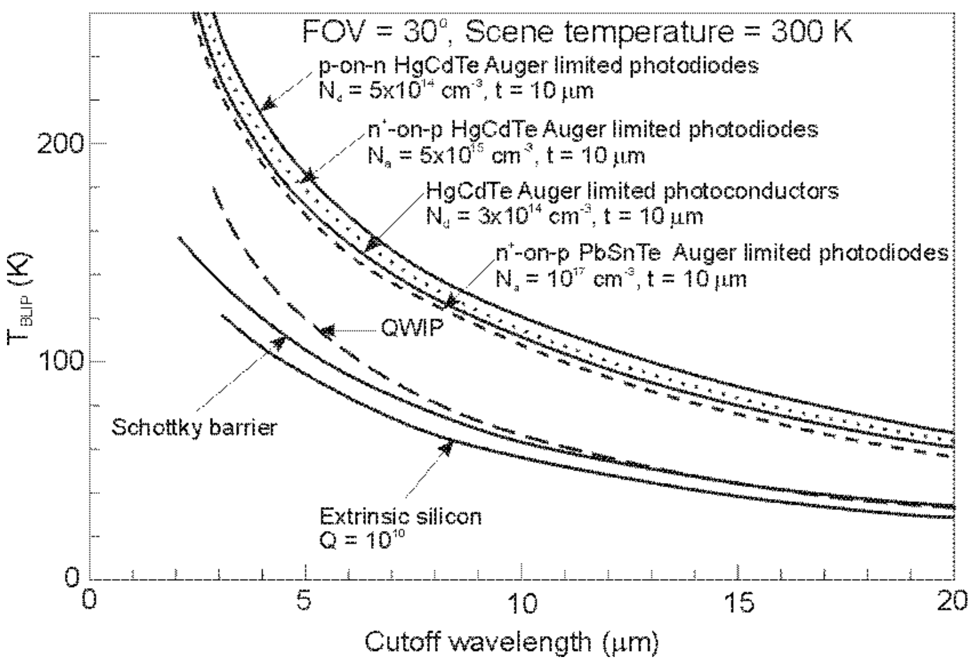

Fig. 2. Estimation of the temperature required for background limited operation of different types of photon detectors. In the calculations FOV = 30° and T_B = 300 K are assumed (after Ref. 6).

To summarize, despite serious competition from alternative technologies and slower progress than expected, HgCdTe is unlikely to be seriously challenged for high-performance applications, applications requiring multispectral capability and fast response. The recent successes of competing cryogenically cooled detectors are due to technological, not fundamental issues. There are good reasons to think that the steady progress in epitaxial technology would make HgCdTe devices much more affordable in the near future. The much higher operating temperature of HgCdTe compared to Schottky barrier devices and low-dimensional solid devices may become a decisive argument in this case. In applications for short-range thermal imaging systems, a serious challenge comes from solid state arrays of thermal detectors (bolometers and pyroelectric), which are expected to take over and increase the market for uncooled short-range imaging systems.

The most important aim in infrared detector technology is to make detectors cheaper and convenient to use. Cooling requirements add considerably to the cost, bulk, weight, power consumption and inconvenience of IR systems. In contrast, the uncooled detectors are lightweight, small in size and convenient to use.

The long-term picture could change as a result of current research activity, both for single-element detectors and arrays. Currently, no known variable-gap material can offer fundamental advantages in terms of performance or cost of production. A challenge may come rather from materials exhibiting higher stability. It is expected that

- Thermal detector arrays will increase in size and improve in thermal sensitivity to a level satisfying high-performance applications at ambient temperature.
- The low-temperature growth of HgCdTe on alternative substrates containing silicon circuits may render Schottky barrier devices with their fundamental physical limitations and stringent cooling requirements.
- The narrow-gap intrinsic semiconductors, possibly those operated in nonequilibrium mode, are likely to be unchallenged for high detectivity and fast single-element and small-array IR systems.
- The situation concerning quantum well structures and superlattices is not clear; however, unique detection capabilities may arise from the low-dimensional solids.

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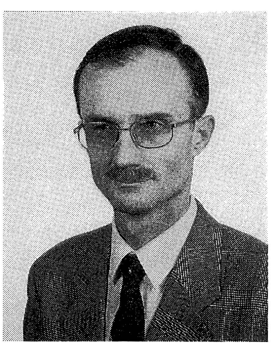

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