# Uniformity of optical absorption in HgCdTe epilayer measured by infrared spectromicroscopy

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Infrared absorption in HgCdTe epitaxial material has been investigated using infrared spectromicroscopy to study the uniformity at dimensions representative of typical infrared detectors. Infrared transmission measurements were performed on HgCdTe material using an infrared beam diameter of 9 $\mu$m. Line scans and area maps of transmission spectra were obtained to investigate statistical variations in infrared absorption. The HgCdTe material demonstrates a high degree of uniformity, with a standard deviation in absorption coefficient near the sensitive turn-on region of less than 3% and standard deviation in extracted $Hg_{1-x}Cd_xTe$ compositon of $3\times10^{-4}$. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1625776]

HgCdTe is a critical material for high performance IR detector focal plane arrays (FPA). The HgCdTe alloy covers the full infrared spectral region, is capable of producing large area FPAs with high operability, and generally provides the best detector performance at a given temperature for detection wavelengths longer than 2 $\mu$m.[1–4] High pixel-to-pixel uniformity is required for IR detector performance in FPAs. HgCdTe photodiode IR detector FPAs typically exhibit characteristics similar to a Gaussian distribution in detector performance figures of merit (i.e., quantum efficiency, dark current, detectivity, etc.). The limiting factors determining the distribution in detector performance are not well understood. Potential sources for pixel nonuniformity may be separated into three categories: HgCdTe optical properties, HgCdTe electrical properties, and read-out circuitry. Nonuniformities in optical properties reflect the conversion of photons to electrons, and may be a result of material nonuniformities including variation in alloy composition or defects. Nonuniformities in electrical properties reflect the ability to collect photogenerated carriers and may also be a result of material fluctuations, but also include nonuniformities in carrier concentration, electron/hole mobility, and the properties of the electrical junction. Nonuniformities in the material may be at dimensions representative of the pixel size, or due to random arrays of nanoscale compositional fluctuations.[5] In this work, we present a study of the uniformity of optical absorption in HgCdTe material using IR transmission microscopy at dimensions representative of IR detectors.

HgCdTe was grown on a CdZnTe (211) substrate by molecular beam epitaxy. In situ spectroscopic ellipsometry measurements and automated feedback control were used during epitaxial growth to provide uniform composition in the growth direction.[6,7] The $Hg_{1-x}Cd_xTe$ alloy composition and layer thickness were determined to be $x=0.226$ and $d=15.8$ $\mu$m, respectively, from room temperature IR transmission measurements. Room temperature IR transmission spectra were measured using (low flux) synchrotron radiation interfaced with a Nicolet Fourier-transform infrared spectrometer and a NicPlan IR microscope. The beam size for the measurement was determined to be $\sim$9 $\mu$m in diameter. An automated microscope stage was used to measure transmission spectra sequentially along a line or in a square area with 10 $\mu$m spacing. The examination of optical absorption uniformity at dimensions of 10 $\mu$m provides a good indicator for IR FPA pixels, where pixel dimensions typically range from 10 to 100 $\mu$m.

The IR transmission spectrum of the layer is shown in Fig. 1, with measurement performed at an arbitrary location on the sample. Variations in optical absorption would be most clearly identified near the transmission turn-on, as indicated by the dotted line in Fig. 1. A three dimensional plot and contour plot of the transmission spectra for a line scan along a distance of 2 mm are shown in Figs. 2(a) and 2(b), respectively. The line scan shows a high degree of uniformity, with subtle variations across each scan. The high

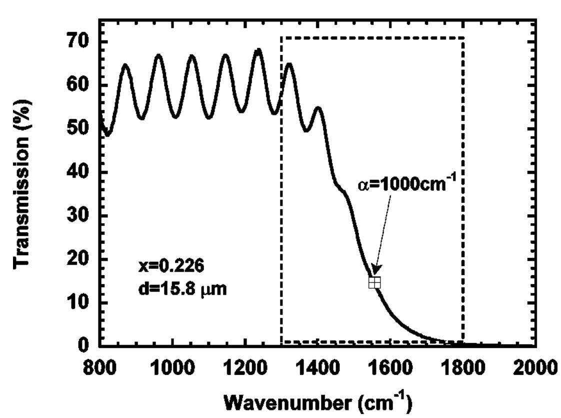


FIG. 1. Room temperature IR transmission spectrum from an arbitrary location on the HgCdTe/CdZnTe epilayer under study. The dotted line indicates the turn-on region of interest for this study, and the $\alpha=1000$ cm$^{-1}$ point on the curve is indicated by an arrow.

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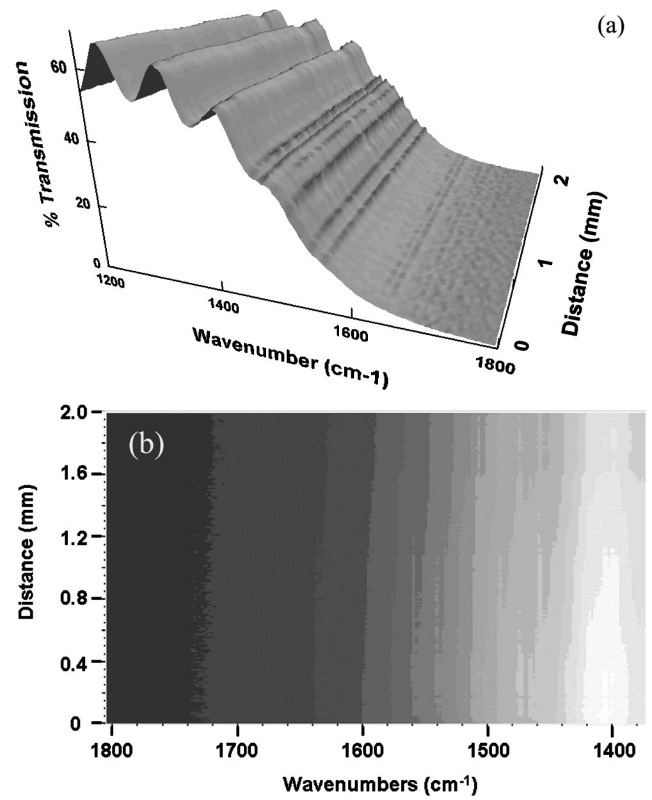


FIG. 2. IR transmission spectra near the turn-on for line scans covering a distance of 2 mm with 10 $\mu$m spacing. Plots are shown in (a) three dimensions and (b) as a contour plot.

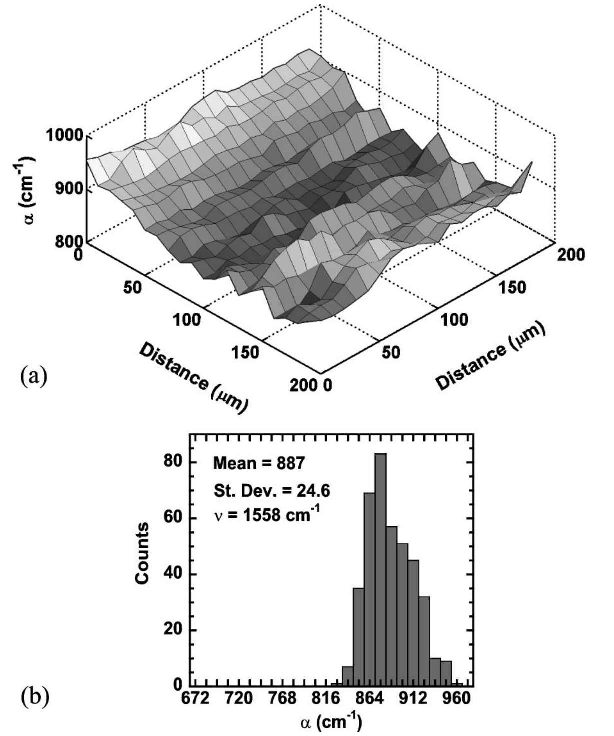


FIG. 3. Plot of (a) absorption coefficient extracted from transmission spectra at a fixed wavenumber of $\nu = 1558\ \mathrm{cm}^{-1}$ for a 200 $\mu$m$\times$200 $\mu$m area and (b) corresponding histogram.

signal-to-noise ratio in the transmission spectra and the ability to reproduce transmission spectra on a single point with less variation than observed across a line scan suggest that the variations are indicative of spatial variations in optical properties rather than noise in the measurement. It should be noted that variations in the optical focus and beam intensity are predicted to show a monotonic change in transmission characteristics rather than the random variations observed in the contour plots. These monotonic variations are observed, where a monotonic decrease in transmission is observed as distance increases from 0 to 2 mm. This overall transmission change is likely due to the decrease in the IR source intensity, where the synchrotron radiation demonstrates a steady intensity decrease with time. This has been confirmed by repeating the measurement in the reverse scan direction, where the net transmission always shows a decrease with time regardless of spatial location. It is of interest to quantitatively examine the spatial variation in optical absorption. The optical absorption coefficient ($\alpha$) may be related to transmission ($T$) using the relation $T = T_0 \exp(-\alpha d)$, where $T_0$ is the peak transmission and $d$ is the HgCdTe layer thickness. This simple relation neglects optical reflections and interference, but provides a good estimate for the absorption coefficient that may be used for comparison of spatial variation. A plot of the extracted absorption coefficient at a wavenumber $\nu = 1558\ \mathrm{cm}^{-1}$ near the transmission turn-on for a scan taken over a 200 $\mu$m$\times$200 $\mu$m area is given in Fig. 3(a). The peak transmission $T_0$ was determined by averaging the transmission over the optically transparent region $1000-1300\ \mathrm{cm}^{-1}$, determining a mean transmission value over three periods of interference fringes. The variation in the absorption coefficient appears to be a random variation. A histogram of the absorption coefficient for the 400 values measured in the area scan shows a distribution as indicated in Fig. 3(b). The absorption coefficient data show a mean value of $887\ \mathrm{cm}^{-1}$ and standard deviation of $24.6\ \mathrm{cm}^{-1}$, representing a 2.8% variation in absorption coefficient at this wavelength. The wavenumber at the $\alpha = 1000\ \mathrm{cm}^{-1}$ (or nearby) point is commonly used to determine the HgCdTe alloy composition in epilayers using previously determined band gap energy versus composition relations.[8,9] Using this procedure, the effective $Hg_{1-x}Cd_xTe$ compositional variation has been extracted for the area scan by obtaining a linear fit to four points centered around the $\alpha = 1000\ \mathrm{cm}^{-1}$ point and determining the wave number and matching HgCdTe composition at that point. The results for the effective compositional variation are shown in Fig. 4(a), where a mean and standard deviation of $x = 0.2256$ and $\sigma = 3.0\times10^{-4}$ are found, respectively, and illustrated in the histogram in Fig. 4(b). It should be noted that the standard deviation of $3.0\times10^{-4}$ exceeds the resolution of the spectrometer, where a $4\ \mathrm{cm}^{-1}$ resolution translates into a resolution of $3.6\times10^{-4}$ at $x = 0.226$. The extracted values do not necessarily represent a pure variation in alloy composition, but rather a complex relation between varying layer thickness, alloy composition, optical absorption coefficient, and optical reflections at interfaces. There appears to be a drift in extracted composition along one spatial direction. At this time, we are uncertain whether this drift is due to true material variations or related to drift in the measurement conditions.

It is well known that IR detector performance is highly sensitive to HgCdTe alloy composition, where conventional figures of merit are zero bias impedance ($R_0A$) and quantum efficiency, which translate into device and FPA figures of

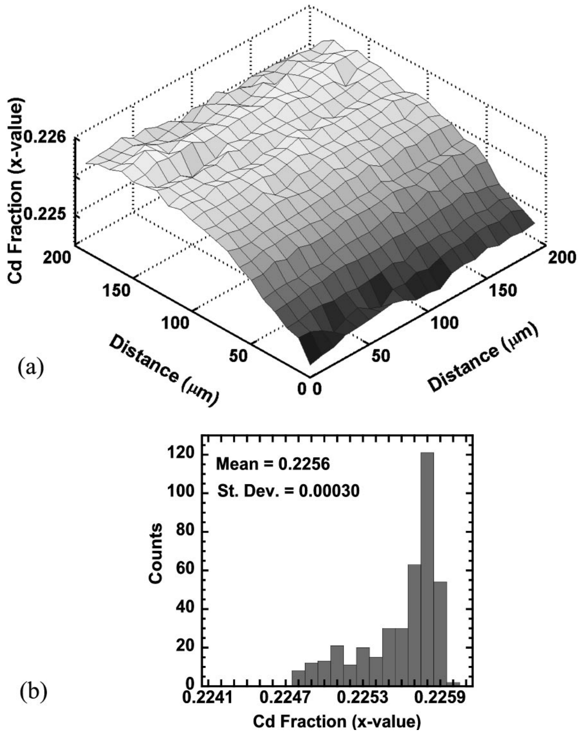


FIG. 4. Plot of (a) HgCdTe composition extracted from the $\alpha = 1000\,\text{cm}^{-1}$ location on fitted transmission spectra for a $200\,\mu\text{m} \times 200\,\mu\text{m}$ area and (b) corresponding histogram.

detectivity and noise equivalent temperature difference. Theoretical relationships between HgCdTe alloy composition and $R_0A$ and quantum efficiency ($\eta$) have been developed for detector design and analysis.[10] If we assume that the effective composition variation in the measured layers will similarly alter the detector performance according to these relationships, we can predict potential detector nonuniformity due to nonuniform IR absorption characteristics. The material for this study is suited for typical long-wave IR applications, where a cutoff wavelength near 11 $\mu$m is predicted at $T = 50$ K. For a mean composition of $x = 0.2256$, estimated values of $R_0A = 7000\,\Omega\,\text{cm}^2$, $\eta(\lambda = 9\,\mu\text{m}) = 0.64$, and $\lambda_C = 11\,\mu\text{m}$ are calculated. The percent variations in these values for $\Delta x = 0.0003$ (corresponding to the determined standard deviation) are $\% R_0A = 2.1$, $\% \eta = 0.19$, and $\% \lambda_C = 0.45$. This analysis suggests that the infrared absorption and HgCdTe compositional uniformity measured at the dimensions of a typical detector pixel are excellent, and are not likely to be a major limiting factor for nonuniformity in HgCdTe IR FPAs. A study of potential nanoscale compositional fluctuations or uniformity in electrical properties and $p-n$ junction characteristics at the microscale may provide further insight into the uniformity limitations in HgCdTe IR FPAs.

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