Infrared photoconductor fabricated with HgTe/CdTe superlattice grown by molecular beam epitaxy

Yueming Qiu, Li He, Jie Li, and Shixin Yuan
Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, People's Republic of China

C. R. Becker and G. Landwehr
Physikalisches Institut der Universität Würzburg an Hubland, D-8700 Würzburg, Germany

(Received 30 July 1992; accepted for publication 9 December 1992)

An infrared photoconductor fabricated with a HgTe/CdTe superlattice grown on a GaAs substrate by molecular beam epitaxy is described here for the first time. The growth procedure, device fabrication, and measurement results are described. The results show that the device has relatively high uniformity and 1000 K black-body detectivity 2.4×10^9 cm Hz$^{1/2}$ W^{-1}. The photoconductivity decay method was used for determining carrier lifetime of the HgTe/CdTe superlattice, the measured lifetime is 12 μs at 77 K, which is the longest lifetime ever reported for HgTe/CdTe superlattices and we believe that the increase of lifetime is mainly due to the reduction of dimensions.

HgTe/CdTe superlattices have been predicted to possess several advantages over HgCdTe alloys for fabrication of high performance long and very long wavelength infrared detectors.[1] These advantages include lower tunneling currents, better control of the band gap, and high temperature operation. HgTe/CdTe superlattices grown by the molecular-beam epitaxy technique[2,3] exhibited properties in good agreement with the theoretical predictions. Harris[4] reported the first high quantum efficiency midwavelength infrared *p*-on-*n* detectors based on HgTe/CdTe superlattices, but there was no report about infrared photoconductor fabrication based on HgTe/CdTe superlattices up to now. In this letter we present the first attempt to make novel photoconductors using MBE-grown HgTe/CdTe superlattices on the (001)GaAs substrate.

The lifetime of optically excited, excess electrons and holes are among the most important parameters of an intrinsic infrared detector material, since they govern the magnitude and frequency response of the signal.[5] Very few lifetime data exist for HgTe/CdTe superlattices because the values are generally quite short and difficult to measure. In this letter we report the longest lifetime ever reported for excess carriers of HgTe/CdTe superlattices.

The sample Q281A was grown on an undoped (001)GaAs substrate. Because of large lattice mismatch between HgTe/CdTe superlattices and GaAs substrates, and to avoid Ga outdiffusion into the superlattice, a 1.4 μm CdTe buffer layer was grown first. The superlattice was grown at 175 °C, and composed of 300 repeats with individual layer thicknesses 16 Å (HgTe) and 19 Å (CdTe). A CdTe top passivation layer of 500 Å was finally grown on the superlattice with the growth temperature unchanged. In fact, the passivation layer is not a complete binary alloy because the growth is performed under a certain Hg pressure, and a ternary with 5%–15% mercury.[6] All the growth processes were monitored simultaneously with reflection high energy electron diffraction.

Figure 1 shows the room-temperature IR transmission spectrum of the superlattice Q281A, measured by a Perkin-Elmer Model 983 spectrophotometer. Only one absorption feature could be observed in the figure indicating that only one subband exists in the HgTe well. The short vertical line in the subband transition (the first heavy hole to the first conduction band) calculated in the envelope function approximation with individual layer thicknesses of 16.15 Å (5 monolayers) HgTe and 19.34 Å (6 monolayers) CdTe coincides with the growth parameter. The above layer thicknesses within the superlattice period were further confirmed by x-ray diffraction measurement. The room-temperature cutoff wavelength of this sample is λ_c (300 K) $=2.90$ μm.

The photodetector was fabricated employing the standard photolithographic techniques. The size of the optical active area was 450×450 μm. Nine detector cells were designed on the chip examined in Fig. 1. The measurements were carried out at 77 K. Figure 2 shows curves of signal, noise, and 1000 K black-body detectivity $D^*_{\rm BB}$ of a typical device with respect to its biasing current I. It can be seen that the signal increases with the current increasing up to 0.26 mA, while the noise rises rapidly when the current increased exceeding 0.18 mA, leading to a serious reduction in $D^*_{\rm BB}$. Therefore $I=0.18$ mA is the best biasing current for the device performance and it was chosen for all the measurements. The relative spectral responses of

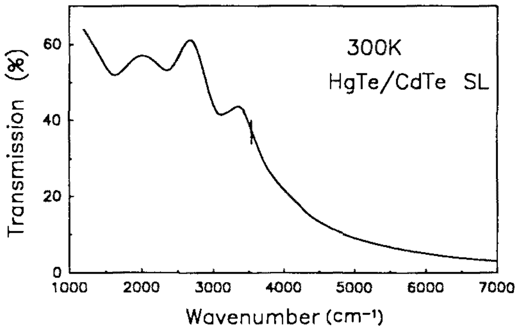

FIG. 1. Room-temperature IR transmission spectra of the superlattice Q281A.

0003-6951/93/101134-03$06.00

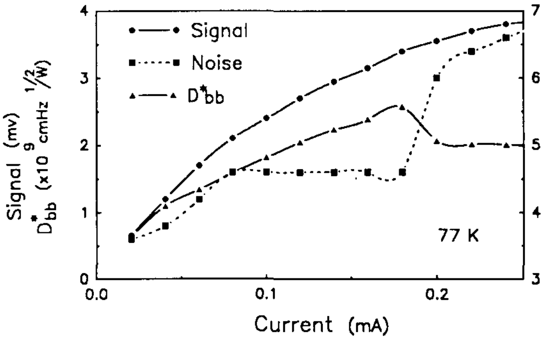

FIG. 2. Signal, noise, and 1000 K black-body detectivity of a typical detector cell versus biasing current at 77 K.

two detector cells of the photoconductor array are shown in Fig. 3. The measurements were carried out at 77 K with a biasing current of 0.18 mA. Each curve was normalized by its peak value. The modulation frequency of incident light was 1000 Hz with a band width of 100 Hz. As can be seen in Fig. 3, the maximum response is at wavelength $\lambda_p=2.82$ μm, and the long-wavelength cutoff λ_c (77 K) for all the nine device cells is within 3.39–3.42 μm while the room-temperature cutoff wavelength $\lambda_{c(300\,\mathrm{K})}=2.90$ μm as we estimated from Fig. 1, in good agreement with the theoretical prediction for superlattice devices.[7] At 77 K with a biasing current $I=0.18$ mA, the average 1000 K black-body detectivity D^*_{BB} is 1.8×10^9 cm Hz$^{1/2}$ W^{-1}, with a maximum D^*_{BB} of 2.4×10^9 cm Hz$^{1/2}$ W^{-1}. The monochromatic detectivity D'_λ was calculated from D^*_{BB} to be 6.2×10^9 cm Hz$^{1/2}$ W^{-1}.

The photoconductivity decay method was used to measure the excess carrier lifetime of the HgTe/CdTe superlattice. Photoconductivity decay curves measured from a typical detector cell are shown in Fig. 4, the measurements were carried out at 77 K. Curve 1 is the photoconductivity decay curve with illumination of a GaAs/GaAlAs pulse laser while curve 2 was measured with a joint illumination of the pulse laser and an ordinary continuous wave (cw) electric lamp. The measurements reveal that there exist trapping centers in the superlattice which can be saturated by the illumination of a cw lamp additional to the pulse laser. Curve simulations revealed that two carrier lifetimes, 71.4 and 12.2 μs dominated the decay process of the photoconductivity signal for curve 1. When the trapping centers were saturated, the photoconductivity signal decreased exponentially with a single carrier lifetime 12.2 μs. Therefore it is obvious that the lifetime of 71.4 μs corresponds to trapping centers in the superlattice. The recombination mechanism for the other lifetime is not exactly known now. It is most probably the Auger recombination because according to Jiang's[8] calculation the Auger lifetime in a quantum well is longer than that in bulk material.

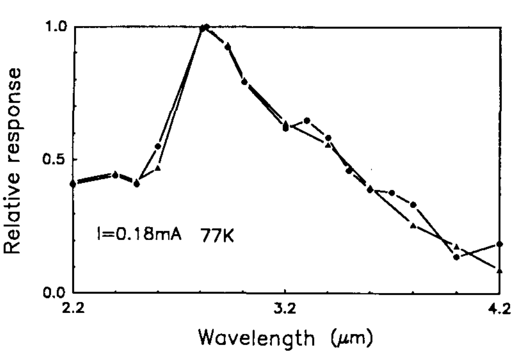

FIG. 3. Two typical detector cells' relative spectral responses at 77 K with a biasing current of 0.18 mA.

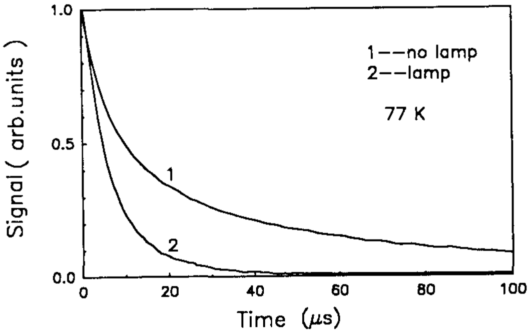

FIG. 4. 77 K photoconductivity decay processess of a typical detector cell illuminated (1) with a GaAs/GaAlAs pulse laser (2) with the GaAs/GaAlAs pulse laser and an ordinary cw electric lamp.

We also propose that the effect of photogenerated carriers at the interface is possibly an important factor responsible for the enhanced performance of our devices. It is known that a charge transfer occurs when a heterojunction is formed, in order to match the Fermi energies of CdTe and HgTe/CdTe superlattice. As a consequence, a local electric field is formed in the vicinities of both the top and bottom interface between the CdTe and HgTe/CdTe superlattice. Clearly, this electric field forces the photogenerated electron-hole pairs to separate spatially, prolonging the carrier lifetime, and therefore increases the responsivity. Because the superlattice active layer is relatively thin as compared with the penetration depth and multiple reflection both top and bottom interfaces should contribute to this spatial separation.

In summary, we have presented the fabrication and performance of a new IR photoconductor with a MBE-grown HgTe/CdTe superlattice and measured the longest carrier lifetime ever reported for HgTe/CdTe superlattices. It is the first time to use HgTe/CdTe superlattices for fabricating photoconductors successfully. Certainly the device performance can be further improved by optimization of crystalline quality, electrical characteristics, and device structural parameters.

This work was supported by the National Committee of Science and Technology. The authors acknowledge Jianmei Zhu, Xingliang Huang, Haimei Gong, Huiguo Qiu, and Lianmei Zhang for their technical assistance.

[1] J. N. Schulman and T. C. McGill, Appl. Phys. Lett. **34**, 663 (1979).

[2] J. P. Baukus, A. T. Hunter, O. J. March, C. E. Jones, G. Y. Wu, S. R. Hetzler, T. C. McGill, and J. P. Faurie, J. Vac. Sci. Technol. A **4**, 2110 (1986).

[3] K. A. Harris, S. Hwang, D. K. Blanks, J. W. Cook, Jr., J. F. Schetzina, N. Otsuka, J. P. Baukus, and A. T. Hunter, Appl. Phys. Lett. **48**, 396 (1986).

[4] K. A. Harris, T. H. Myers, R. W. Yanka, L. M. Mohnkern, and N. Otsuka, J. Vac. Sci. Technol. B **9**, 1752 (1991).

[5] D. Long and J. L. Schmit, in *Semiconductors and Semimetals*, edited by R. K. Willardson and A. C. Beer (Academic, New York, 1970), Vol. 5, Chap. 5.

[6] X. Chu, S. Sivananthan, and J. P. Faurie, Superlattices and Microstruct. **4**, 173 (1988).

[7] Y. Guldner, G. Bastard, and M. Voos, J. Appl. Phys. **57**, 1403 (1985).

[8] Y. Jiang, M. C. Teich, and W. I. Wang, J. Appl. Phys. **69**, 6869 (1991).

Published without author corrections