Mercury-Cadmium-Telluride thin layers as sub-THz and IR detectors

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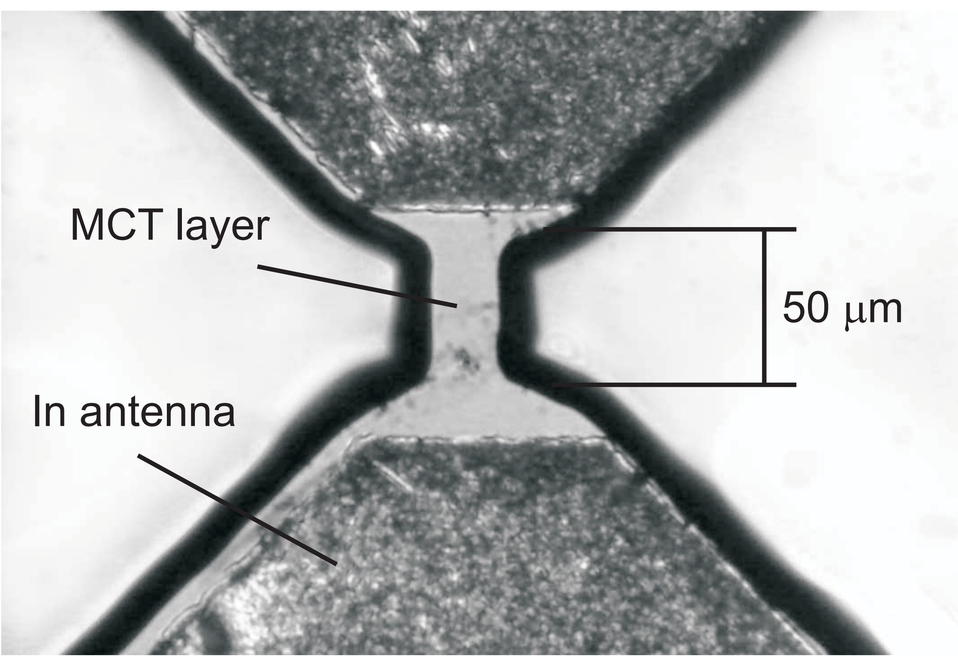
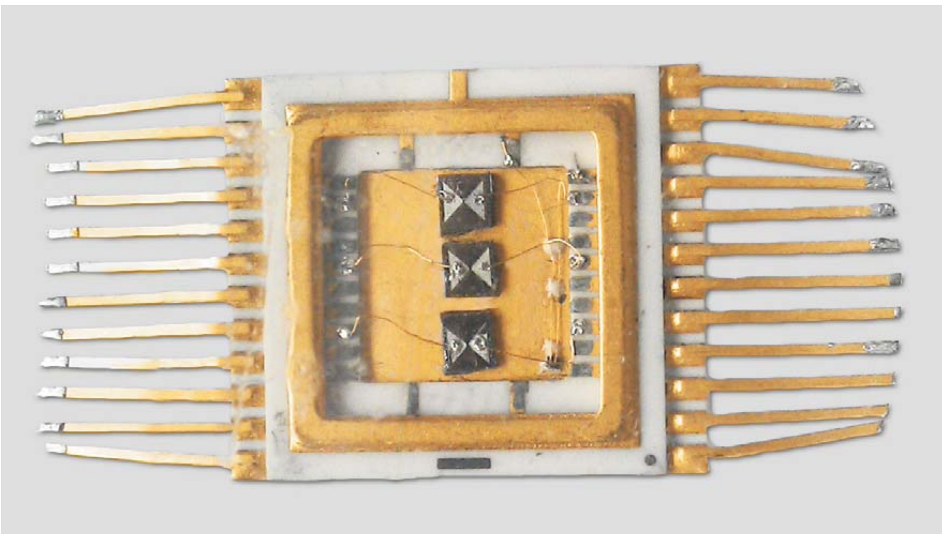
Bi-color un-cooled and cooled to 78 K narrow-gap mercury-cadmium-telluride (MCT) semiconductor thin layers with antennas were considered both as sub-terahertz (sub-THz) direct detection bolometers, and 3 to 10 μm infrared (IR) photoconductors. Noise equivalent power (NEP) of MCT sub-THz detectors at $\nu \approx 140$ GHz was estimated as well as its IR response at T = 78 K and 300 K. The characteristics of such bi-color detectors can be controlled and improved by selection of parameters of initial layers and of the antennas configuration.

Mechanisms of responsivity





IR thin-film photoconductors: the changes in conductivity rising under IR illumination result in photoconductor response due to valence-to-conduction band transitions.

MCT uncooled or not deeply cooled hot electron bolometers (HEBs): three different responsible effects - (i) Dember effect (photo-diffusion effect) contribution, (ii) thermo-electromotive contribution, and (iii) contribution associated with changes in the concentration of free carriers [Dobrovolski, V., and Sizov, F., "THz/sub-THz bolometer based on electron heating in a semiconductor waveguide," Opto-Electron. Rev. 18, 250–258 (2010)]. According to this model, the wave with frequency, lower compared to space charge Maxwell relaxation frequency, is inputted to the semiconductor layer via metallic contact-antenna and propagates in it as in a bipolar semiconductor waveguide, heats electrons and holes.

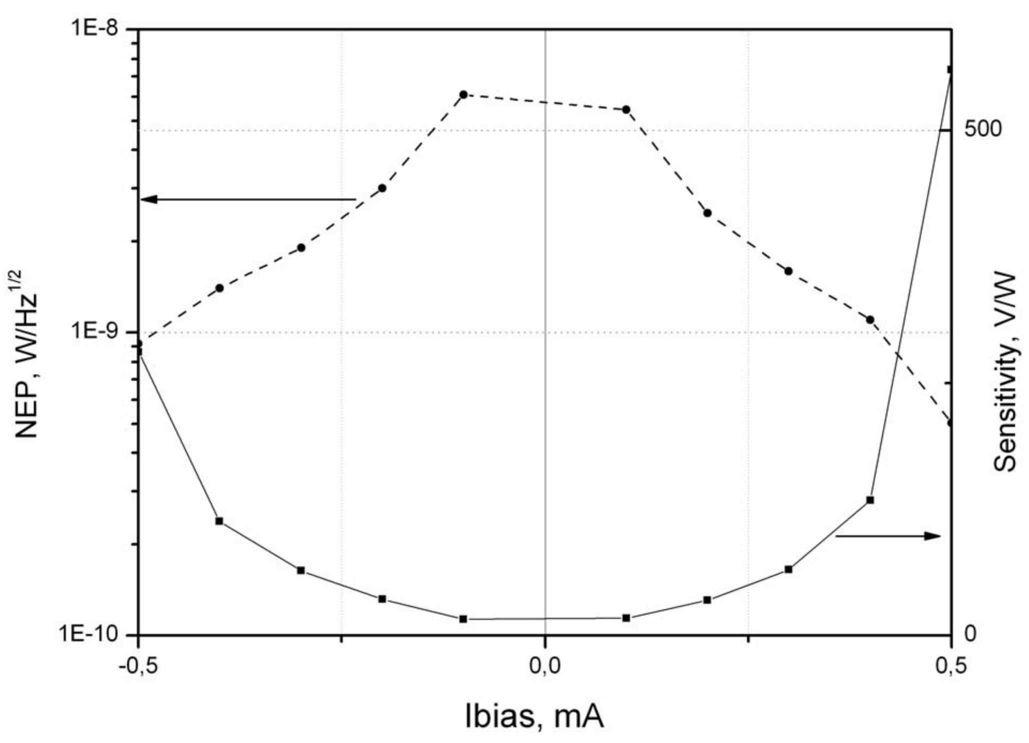
Here THz/sub-THz response of MCT detectors is observed in n-type layers with electron concentration $n_{78K} \approx 2\cdot10^{14}$ cm^{-3} at T = 78 K for chemical composition $x \approx 0.216$ and MCT layers initial thicknesses 5.3 μm. These layers at T = 300 K have intrinsic conductivity with carriers concentration $n_i \approx 2.5\cdot10^{16}$ cm^{-3}. The resistances of samples at room temperature condition were ~300-400 Ohm depending on their dimensions after etching.

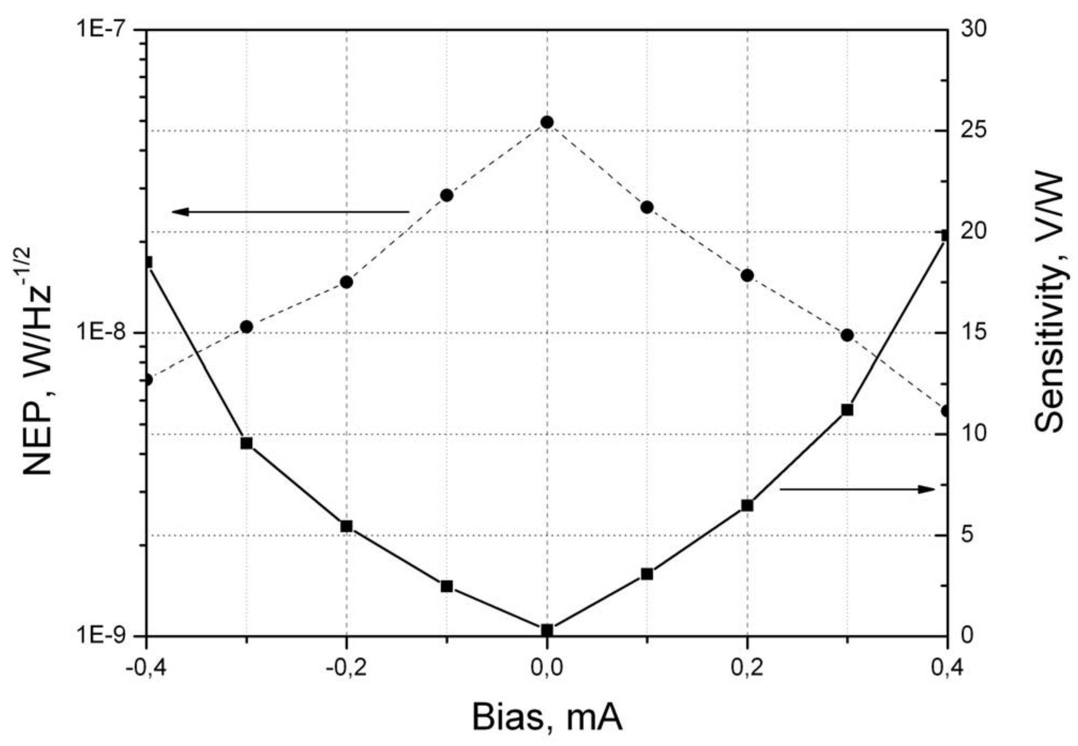
The design and dimensions of antennas were calculated for the best detector sensitivity within the 150–300-GHz frequency band. To decrease the influence of HEB (MCT epitaxial layer) on antenna parameters, the size of sensitive element has to be much less than antenna's size, and antenna's area must be optimized to frequency of incident radiation. We propose the bow-tie antenna with 90^0 divergence angle of side of antenna from the center of sensitive element, what allows entering of the greater part of the incoming radiation into a sensitive element. At the same time such construction of detector allows using of symmetric and identical area current contacts (antenna blades) for registration of photocurrent at the detecting in IR spectral region. Thus detector of such construction can operate as bi-color IR and sub-THz one.

Photo of THz/sub-THz and IR detector with bow-tie antenna and those, assembled in frame.

THz/sub-THz responsivity

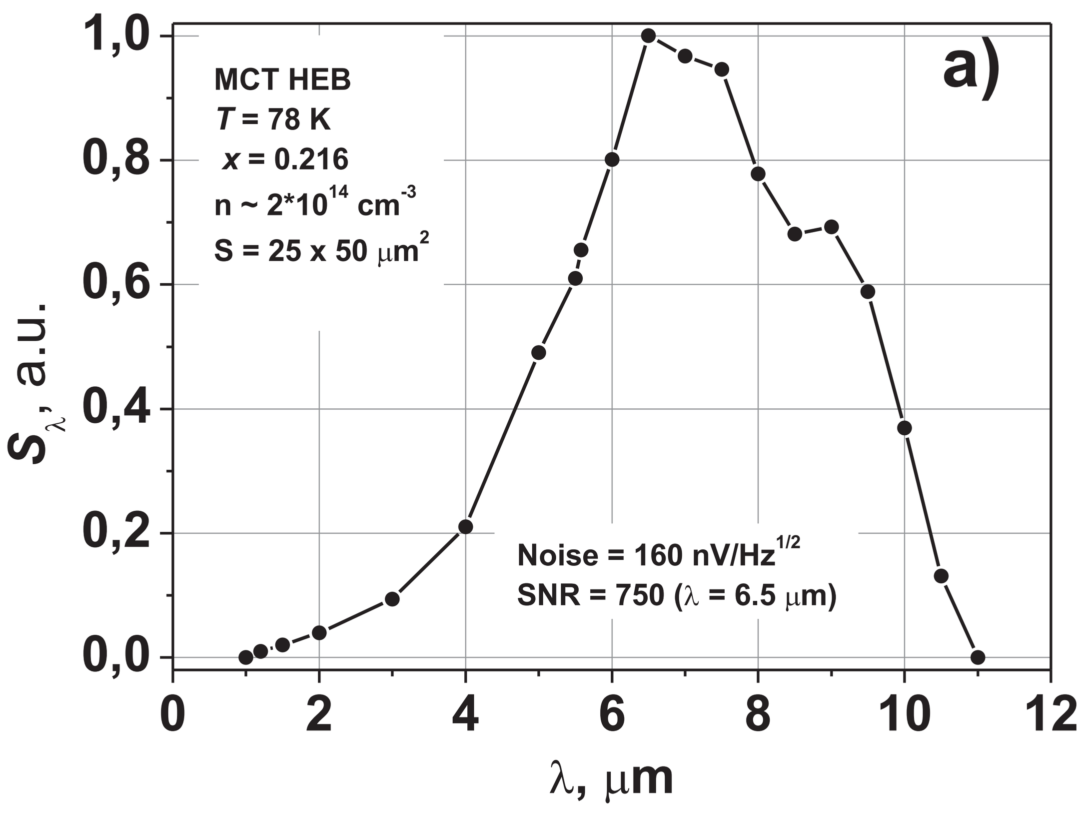
For such a detector used for sensing of a sub-THz radiation at ν = 140 GHz the best measured noise equivalent power values were $NEP_{300K} \approx 4.5\cdot10^{-10}$ W/Hz$^{1/2}$ and $NEP_{78K} \approx 5\cdot10^{-9}$ W/Hz$^{1/2}$. The noise level was measured by lock-in amplifier (Stanford SR 830) for which the intrinsic input noise is 6 nV/Hz$^{1/2}$. Figure shows the responsivity (a), noise-equivalent power and volt-watt sensitivity (b) in dependence of sample bias at T=300 K. The measured values of responsivity were R ~ 600 V/W at 0.5 mA bias (T=300K) and R ~ 20 V/W at 0.4 mA bias (T = 78 K). The worth NEP value at 78 K compared to that one at T = 300 K can be explained by different components contribution of hot-carrier MCT bolometer responsivity vs temperature. Concerning the temperatures at which the maximal response could be observed for given sample our calculation shows that it is near 110 120 K with strong decreasing both to 78K and 300K temperatures. On the other hand noises at 78 K temperature will be much greater because resistance of the samples will be increased from 300-400 Ohm to 2400-2600 Ohm.

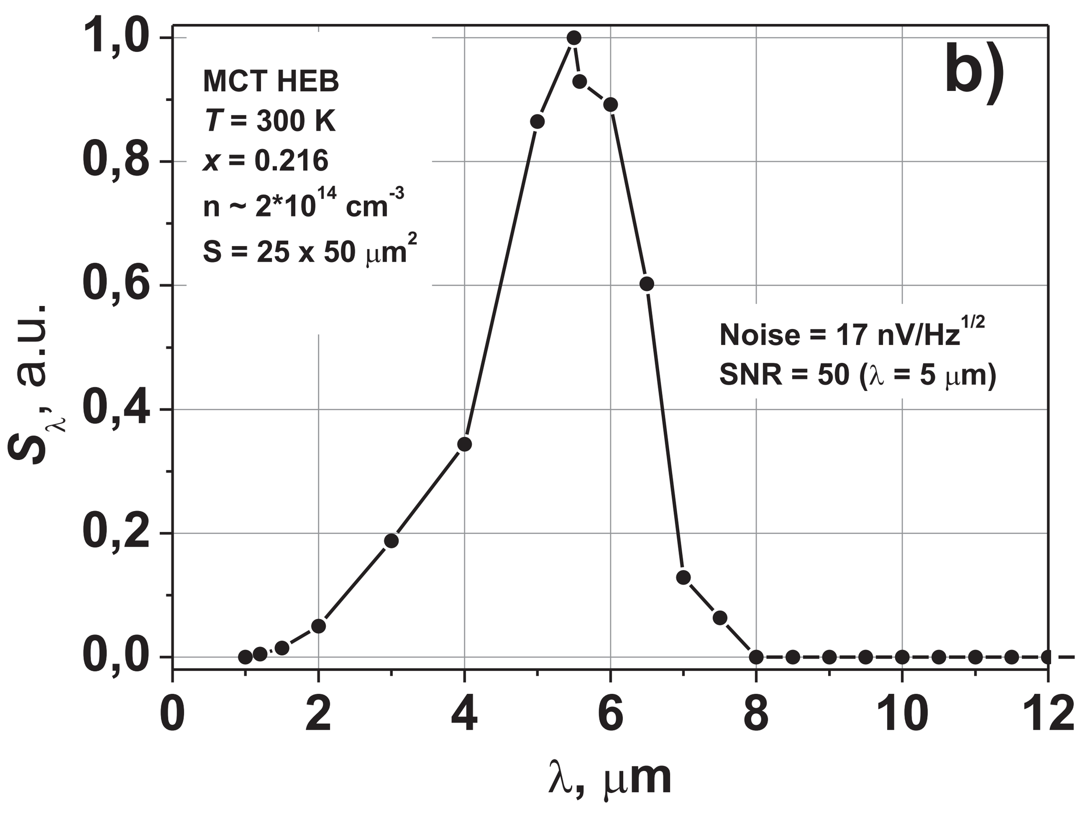




Noise-equivalent power and volt-watt sensitivity in dependence of sample bias at T = 300 K (a) and T = 78 K (b). In both cases detector was illuminated by 140 GHz radiation. Gain of antenna was taken as G = 1. $NEP_{300K} \approx 4.5\cdot10^{-10}$ W/Hz$^{1/2}$ and $NEP_{78K} \approx 5\cdot10^{-9}$ W/Hz$^{1/2}$.

IR photo-response





Responsivity spectra of MCT detector in IR region: a) T = 78 K, b) T = 300 K.

The globar with the temperature T = 1600^0 C was used as a source of IR radiation and IR monochromator as a spectral instrument with 0.1 μm spectral resolution. Detector was current biased with I_{bias}=50–100 μA. The base of the IR response even at T=300K is that the band-to-band optical absorption is strong in direct-gap MCT semiconductor. Because of high value of $N_{ph} \sim 10^{19}$cm^{-2} c^{-1} from globar ($T_{globar}=1600^0$ C) in 5.0–5.5 μm spectral range (after monochromator) in the stationary regime of photoconductivity (modulation frequency f=300Hz), the ratio of photo-induced carriers $\Delta n = g(d)\cdot\tau \sim 1\cdot10^{15}$ cm^{-3} and that of intrinsic concentration $n_i \sim 2.5\cdot10^{16}$ cm^{-3} is getting $\Delta n/n_i \sim 4\cdot10^{-2}$ that is quite sufficient to observe the signal-to-noise ratio ~50 with lock-in amplifier (Stanford SR 830). Here the measured $\tau \sim 7\cdot10^{-8}$ s in such n-type layers. At background temperature T_{BLIP} = 300 K (BLIP is the background limited performance), and quantum efficiency $\eta \approx 1$ photoconductors can reach detectivity $D^* \approx 4\cdot10^8$ cm·Hz$^{1/2}$/W at $\lambda_{cut-off}$ operating region.

Conclusions

The possibility of realization of bi-color un-cooled and cooled to 78K IR and THz/sub-THz detectors based on narrow-gap MCT semiconductor has been shown. Noise equivalent power of MCT sub-THz detectors at $\nu \approx 140$ GHz was estimated as well as its IR (3-10 μm) response at T = 78K and 300K and showed relatively good quality of such detectors. At low radiation powers, MCT HEB and IR detectors are square-law detectors in which the response is proportional to the incoming power, and both IR and THz/sub-THz detectors can be assembled into arrays. Mercury cadmium telluride (MCT) THz (bolometer-type) and IR detectors, that allow multielement array implementation with integrated silicon readouts, thus making possible on-chip signal processing and real-time focal plane image acquisition. They could be applied for customs and postal packages control, food production quality control, security and for any application where low cost, portability and uncooled operation of THz are the main factors.

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