New generation of infrared radiation detectors: MCT detectors with fiber input


Abstract

New generation of mercury-cadmium telluride (MCT) high performance infrared radiation (IR) detectors with fiber input has been developed and fabricated. This new product is originated from 25 years experience in MCT detectors and IR fiber optics technologies. Range of products includes single- and multi-element detectors designed for registration of optical signals in wide-band and narrow-band mode in spectral range from 2 to 18 μm. Detectors are manufactured in integrated or modular design, which includes package, sensitive element, cooling system, operating temperature sensor, optical elements such as narrow band-pass filter and/or lens and/or different kind of optical window, optical connection unit and fiber pig-tail or fiber cable. Cooling system options include thermoelectric cooler, long-holding time dewar filled with liquid nitrogen, Joule-Thomson micro-liquidizer and Stirling-cycle cooler. Registered infrared radiation is delivered to sensitive area of detector through either Polycrystalline InfraRed (PIR) Fiber (4 - 18 μm) or Chalcogenide IR-glass (CIR-Fiber) (2 - 6 μm). Unique feature intrinsic to Hg_{1-x}Cd_xTe (MCT) alloys to form continuous series of alloy compositions "x" with proportionally changed energy gap $E_g(x, T)$ allows to tune spectral responsivity of detector element with ordered spectral range that is to use every time the highest sensitive detector.

Keywords: semiconductors A, amorphous materials A, light absorption and reflection D and E,

1. Introduction

Optical sensor or fiber is a part of almost every state-of-the-art solid-state infrared opto-electronic component. That optical sensor or fiber is based on high-quality single-crystal or polycrystalline materials, which are mostly alloys and compounds. Real progress in manufacturing technology of alloys and compounds provides good opportunity to create new generation of opto-electronic components and systems based on those. All above-mentioned statements are related directly to opto-electronic components and systems designated for detection and processing of infrared radiation (IR) in the spectral range longer than 1.5 μm traditionally divided on Short-Wave (SWIR) range from 1.5 to 2.5 μm, Medium-Wave (MWIR) range from 3.0 to 5.5 μm, Long-Wave (LWIR) range from 8.0 to 14.0 μm and Very Long-Wave (VLWIR) range from 14.0 to 20.0 μm. There was in the past, there is nowadays and there will be in the future a great interest in creation of real-time non-contact optical metering systems to characterize objects by emitted or reflected or absorbed infrared radiation with wavelength longer than 1.5 μm, which are difficult of access or beyond direct optical access [1].

Those objects are different gases, organic and non-organic liquid and solid substances, coherent and non-coherent sources emitting radiation within narrow spectral lines, heated objects emitting thermal radiation according to those local temperatures. For example, measured parameters could be local surface temperature of different parts of airplane or ship or train equipment having no direct optical access or concentration of harmful gas in remote cavity or local wall temperature in narrow long bent tube, for example, in industrial boroscopy or medical endoscopy. That special real-time non-contact optical metering system can be developed and operates effectively if and any there are high performance infrared radiation sensor and high-quality reliable low optical loss infrared fiber both tuned to ordered spectral range (line). For effective operation of the system is required proper conjunction between sensor’s sensitive element and fiber output.

Now we are in position to offer new high-tech product: MCT detectors with fiber input. Those detectors are reliable industrial level products. In Russia MCT IR sensors as a part of new product were originated first from scientific school founded by Russian Academician by-cororessor Mr. Leonid Kurbatov [2] and IR fibers were originated first from scientific school founded by Russian Academician Nobel Prize winner Mr. Alexander Prokhorov [3-6].

2. MCT alloys and IR sensors

Solid ternary alloys Mercury-Cadmium Telluride or MCT are alloys of two binary compounds HgTe and CdTe. Chemical formula is (HgTe)$_{1-x}$ + (CdTe)$_x$ = Hg$_{1-x}$Cd$_x$Te, where composition “x” is mole fraction of CdTe. Some unique features are intrinsic to Hg$_{1-x}$Cd$_x$Te alloys. First, Hg$_{1-x}$Cd$_x$Te forms continuous series of alloy compositions “x” with proportionally changed energy gap $E_g(x, T)$ [7, 8]. Energy gap $E_g(x, T)$ is varied almost linearly from 0.0 to 1.6 eV on semiconductor side of Hg$_{1-x}$Cd$_x$Te when “x” is varied in the range 0.14 x 1.0. Second, there is a possibility to grow uniform, high purity and crystalline perfect Hg$_{1-x}$Cd$_x$Te material in whole range of “x” from 0.0 to 1.0 with optimal electro-physical, electro-optical and
other properties, which are needful to manufacture high quality infrared radiation sensors in the range from 1.5 to 20 μm. A. m. features of MCT material provided opportunity to fabricate a wide nomenclature of infrared radiation sensors with excellent sensitivity and attractive applicability.

Conventional series of MCT IR sensors include:

- Sensors assembled on the base of dewar filled by liquid nitrogen. Availability of miniaturized Dewars with holding time up to 12 hours allows using those sensors in much number of research and industrial applications.
- Single- and multi-element sensors provided with Joule-Thomson micro-liquidizer or Stirling-cycle cooler. Those sensors can operate in autonomous or semi-autonomous mode for a long period of time. Such sensors are used often in severe conditions of exploitation.
- Dewar type sensors and sensors provided with Joule-Thomson micro-liquidizer or Stirling-cycle cooler can be fabricated either photoconductive (PC) or photovoltaic (PV) covering MW & LW spectral ranges from 3 to 20 μm. Detectivity D*(\( \epsilon_p \)) values are limited by background flux density fluctuations (BLIP) at operation temperature of sensitive element 78 K so that D*(\( \epsilon_p \))=4,0 mW/cm²

SW spectral range. Spectral transmitting curve of CIR-fibers for MW spectral range and partly for glass (As-Chalcogenide InfraRed glasses based on arsenic trisulfide for MW & LW spectral ranges: CIR-fibers (Chalcogenide Manufacturing). Nowadays there are available two basic types of IR fibers that satisfy requirements [3-6].

Nowadays there are a few materials do have properties necessary for manufacturing uniform long-length IR fibers with stable optical performance and attractive applicability features. Many years development and studying of IR fibers technologies for MW & LW spectral ranges led to final selection of proper base materials, forming of perspective IR fiber design concept and creation of effective manufacturing technology coping to customer requirements [3-6].

Nowadays there are available two basic types of IR fibers for MW & LW spectral ranges: CIR-fibers (Chalcogenide InfraRed glass fibers) and PIR-fibers (Polycrystalline InfraRed fibers).** Chalcogenide InfraRed glasses based on arsenic trisulfide glass (As2S3) are the best materials for manufacturing high-quality IR fibers for MW spectral range and partly for SW spectral range. Spectral transmitting curve of CIR-fiber is presented on Fig. 1. Design concept is Core/Clad graded refractive index structure with double polymer coating for high flexibility and protection. Precise sized core/clad half-finished CIR-fibers are manufactured by drawing. Typical specification of CIR-fibers is presented in Table 1.

Silver Chalcogenide ternary alloys are alloys of two binary compounds AgCl and AgBr. Both compounds are sensitive to visible light and hydroscopic. These alloys are the best materials for manufacturing high-quality IR fibers for LW spectral range and partly for MW spectral range. Spectral transmitting curve of PIR-fiber is presented on Fig. 1. Design concept is Core/Clad graded refractive index structure with PolyEtherEtherKetone (PEEK) coating. PEEK coating covers hermetically core/clad structure of fiber and protects it against mechanical damage, visible and thermal irradiation and chemical corrosion. Precise sized core/clad half-finished PIR-fibers are manufactured by extrusion. Typical specification of PIR-fibers is presented in Table 1.

4. Design concept of fibered detectors

High-sensitive MCT IR sensors include in set cooling system, which provides proper operation temperature of sensitive element(s) (see Chapter 2). Therefore sensitive element(s) are mounted on cooled header within vacuum tight sealed package. Package cavity can be under vacuum of filled by low thermal conductivity gas or dry gas. IR Sensor with cooling system is carefully balanced in respect to heat flows to cooled header that guarantees required level of operation temperature and hence high level of opto-electronic performance. Effective design of fibered detector is compromise between necessity do not break thermal balance around sensitive element and desire to collect as much as possible of optical signal power irradiated from butt-end of fiber. For the first reason direct intimate contact between butt-end plane of fiber and front plane of sensitive element is excluded absolutely. Taking into account second provision it is desirable to use outside optical adjustment unit with capability to collect of diverged radiation beam and to direct it precisely onto active area of sensitive element within sealed package. Minimal level of optical losses should be got. In this concern we implement two basic design concepts presented on Fig. 2:

- Design with autonomous MCT IR sensor and separate outside optical adjustment unit (Fig. 2 a and b). Optical unit including lens (objective) and optionally changeable optical filter is fixed on sensor package. Connection of fiber to sensor is provided via optical SMA connector. In this case MCT IR sensor can be used separately as normal IR detector. Optical adjustment unit is changeable.
- Design with IR sensor and optical adjustment unit is coupled after proper tuning (Fig. 2 c). In this case MCT IR sensor can be tested. Those detectors were TE cooled detectors for MW spectral range. Design concept can be realized in MCT IR sensors which package includes autonomous thermal insulating dewar as integral part of package.

5. Fibered detectors performance

Different MCT fibered detectors were fabricated and tested. Those detectors were TE cooled detectors for MW spectral range. Fibers are issued under trademark €F registered by A. R. T. Photonics GmbH, Germany.
Absolute value of transmission

Fig. 1. Typical transmission spectra of CIR-fiber cable 750/850 µm Core/Clad diameters and PIR-fiber cable 900/1000 µm Core/Clad diameters both with length of 1.5 meter

Table 1

<table>
<thead>
<tr>
<th>Ord. No.</th>
<th>Parameter Name</th>
<th>CIR-fiber cables</th>
<th>PIR-fiber cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transmission range</td>
<td>From 2.0 to 6.0 µm</td>
<td>From 4.0 to 18.0 µm</td>
</tr>
<tr>
<td>2</td>
<td>Core/Clad structure materials</td>
<td>Chalcogenide glasses As₂S₃/As-S (amorphous)</td>
<td>Ternary alloys AgCl: AgBr (polycrystalline)</td>
</tr>
<tr>
<td>3</td>
<td>Core/Clad diameter</td>
<td>200-800/300-950 µm</td>
<td>400/500; 630/700; 900/1000 µm</td>
</tr>
<tr>
<td>4</td>
<td>Core refractive index</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>5</td>
<td>Optical losses</td>
<td>0.2 dB/m at wavelengths 2-4 µm</td>
<td>0.2-0.3 dB at wavelength 10.6 µm</td>
</tr>
<tr>
<td>6</td>
<td>Ambient temperature range for operation</td>
<td>From 280 to 400 K</td>
<td>From 73 to 523 K</td>
</tr>
<tr>
<td>7</td>
<td>Max length of cable available</td>
<td>Up to 20-30 meters</td>
<td>Up to 20-30 meters</td>
</tr>
</tbody>
</table>

operation in MWIR (3.0-5.5 µm) spectral range (Fig. 3) and dewar type detectors for operation in LWIR (8.0-14.0 µm) spectral range. A few detectors were provided additionally by narrow band-pass filter to detect intensity of radiation absorbed within narrow known in advance absorption lines of different gases. For example, TE cooled detectors were provided by proper narrow band-pass filters to detect radiation intensity within absorption line of methane (3.25 µm) and hydrocarbons (3.43 µm).

Generally speaking performance and behavior of fibered MCT IR detectors is very similar to normal MCT IR detectors. D*(ν) value of fibered detectors was 2-4 times lower that initial one (see Chapter 2) due to optical losses caused by reflection and divergence of radiation beam. But this is not extraordinary high level of signal power losses. Optical losses up to 50% (2 times) are considered as not critical in systems with normal IR detectors. Using of ultimate performance MCT IR sensors as a part of fibered detectors will allow manufacturing MCT IR fibered detectors with opto-electronic performance acceptable for almost every practical need of customer.

Acknowledgments

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Fig 3. Miniaturized fibered MCT photoreceiver: (1) – heat-sink; (2) case containing PC MCT MWIR TE cooled detector, plate with changeable filter and focusing lens, (3) – electrical connectors on both sides of the case; (4) – adjustable optical unit with optical SMA connector; (5) – optical fiber cable and (6) – preamplifier box. Overall dimensions: Length x Width x Height – 87.5 x 66.0 x 70.5 mm.

References

Fig. 2. Design concept of MCT infrared radiation detectors with fiber input: a) – and b) – design with outside detachable optical coupler and c) – design with fixed optical coupler.