PPTF

Polish Technological Platform on Photonics

Request for extension of exemption for the use of mercury and cadmium in infrared detectors,
Annex IV of RoHS Directive 2011/65/EU

20.01.2023

Exemption Request Form

Date of submission: **20 January 2023**

1. Name and contact details

1) Name and contact details of applicant:

Company:	**Polish Technological Platform on Photonics**	Tel.:	**+48 22 733 54 10**
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2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

X Request for extension of existing exemption in Annex IV

☐ Request for deletion of existing exemption in:

☐ Provision of information referring to an existing specific exemption in:

☐ Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: **1c.**

Proposed or existing wording: **Cadmium and Mercury in infra-red detectors.**

Duration where applicable: **Maximum validity period of seven years**

☐ Other:

3. Summary of the exemption request / revocation request

The application requests extension of exemption for the use of mercury and cadmium in infrared detectors for monitoring and control instruments including industrial monitoring and control instruments.

Infrared measurement technology has various advantages over different techniques - it is highly sensitive, selective and very fast, allowing for real-time measurement of various substances, gases and fluids. The most common measurement technique is infrared spectroscopy. It covers a range of techniques, mostly based on absorption spectroscopy. As with all spectroscopic techniques, it can be used to identify and study chemicals.

Especially the MWIR (3-8 μm) and LWIR (8-14 μm) IR spectra are useful for analytical purposes:

- Many gases have only in the MWiR significantly strong absorption features.
- The fundamental absorptions of many gases are much stronger in the MWIR than the overtone bands in the SWIR (e.g., CO_2 and CH_4).
- Separation of the absorption “fingerprints” of different molecules is easier in the MWIR and LWIR.

The most sensitive IR devices are based on photon detectors – i.e. compound semiconductors using II-VI, III-V and IV-VI compounds. The variable band gap $Hg_{1-x}Cd_xTe$ (also called in short HgCdTe or MCT) has been undeniably the champion among the large variety of material systems, offering 2x up to 100x better detectivity levels in the MWIR and especially LWIR spectrum.

There are possible substitutes used in less demanding measurement applications – III-V compound semiconductor detectors. However, despite many years of development there have not yet been any commercially available detectors matching MCT detectors in terms of detectivity.

4. Technical description of the exemption request / revocation request

(A) Description of the concerned application:

1. To which EEE is the exemption request/information relevant?

   Name of applications or products:

Monitoring and control devices including industrial monitoring and control devices

Infrared radiation detection

Infrared radiation has been known about and used practically for over two centuries. The world around us and we ourselves are powerful sources of invisible short wavelength (SWIR; 0.8 μm to 3 μm) middle wavelength (MWIR; 3 μm to 8 μm), long wavelength (LWIR; 8 μm to 14 μm) and very long wavelength (VLWIR; >14 μm) infrared radiation. The names and classifications of these subregions are conventions, and are only loosely based on the relative molecular or electromagnetic properties. Infrared radiation carries comprehensive information about objects that generate or interact with the radiation.

The first decades of the 21st century have brought rapid development in infrared (IR) technology and expansion of its applications in military (night vision, smart munitions, navigation, weapon detection), industrial (non-contact temperature measurements, communications, aerospace, medical diagnostics), environmental (atmospheric sounding, pollution control, meteorology, environmental monitoring), academic (e.g., astronomy) and medical diagnostics equipment.

Infrared spectroscopy

Infrared measurement technology has various advantages over different techniques - it is highly sensitive, selective and very fast, allowing for real-time measurement of various substances, gases and fluids [1]. The most common measurement technique is infrared spectroscopy. It covers a range of techniques, mostly based on absorption spectroscopy. As with all spectroscopic techniques, it can be used to identify and study chemicals. Infrared spectroscopy exploits the fact that molecules absorb specific frequencies that are characteristic of their structure. These absorptions are resonant frequencies, i.e. the frequency of the absorbed radiation matches the frequency of the bond or group that vibrates. The energies are determined by the shape of the molecular potential energy surfaces, the masses of the atoms, and the associated vibronic coupling.

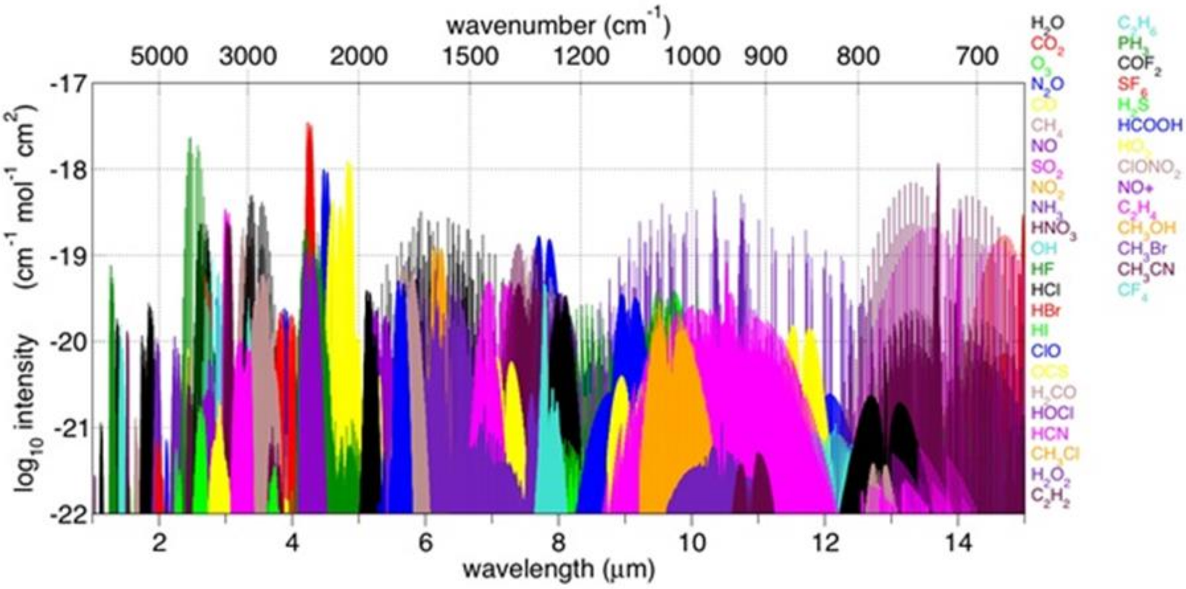
Infrared spectroscopy is a very useful technique across the whole spectrum of infrared radiation. Nevertheless, Mid-IR gas sensing is especially important in the most popular industrial and medical applications. This is due to the fact that the most important gases are molecular gases and have strong rotational-vibrational absorptions in the Mid-IR spectral range.

Mid-IR absorption is the usual measurement technique for CO_2. It is also most frequently used for hydrocarbons and quite often for CO measurements. **Sensitivity** is not the main reason to use Mid-IR gas-sensing devices. Other sensor principles may be more sensitive. But for industrial and medical applications **selectivity** is of equal importance. Due to the fact that the Mid-IR “fingerprint” of different gas molecules can be spectrally separated, a high degree of selectivity can be achieved, and, e.g., false alarms by cross-interference to background gases are avoided. A further reason to favor Mid-IR gas sensing against other technologies is **stability**. For many applications, e.g., infrastructure installations, a sensor needs to have a long lifetime, stable response with almost no maintenance, giving some indication that it is working properly. This can be achieved with Mid-IR devices. [1]

From an application point of view, the Mid IR has the following advantages over Near-IR gas-measuring systems:

- Many gases have only in the MWiR significantly strong absorption features.
- The fundamental absorptions of many gases are much stronger in the MWIR than the overtone bands in the SWIR (e.g., CO2 and CH4).
- Separation of the absorption “fingerprints” of different molecules is easier in the MWIR and LWIR.

Figure 1 - Infrared absorption bands of different gases in the Mid-IR spectrum



Analysis of gases

A variety of spectroscopic techniques are used in gas analysis and sensing – increasingly important fields – crucial in atmosphere monitoring, emission control and industrial processes efficiency. They are implemented more and more often on a mass scale to ensure the well-being of humanity and the environment around us. A thorough understanding of those techniques enables the development of modern, cost-effective and efficient gas analysis solutions, best suited to specific applications and squeezing the most out of the laser spectroscopy potential.

The most selective and sensitive analytical methods are based on laser spectroscopy devices:

- MCT detectors are used in **NDIR (non-dispersive infrared) spectrometers**, for example used to selectively detect isotopic variations of CO2, which takes advantage of difference between the spectra of CO2 with different C isotopes and therefore enables marking with other isotopes.

- Another equipment type are CRDS systems (Cavity Ring-Down Spectroscopy). The principle is absorption spectroscopy, whose sensitivity is enhanced by utilising an external cavity. Those systems are entering the commercial market and show great potential, as they are robust and compact, all while showing great detection capabilities. (https://laserbreathtechnology.com/products/laserbreath001)
- Also utilising absorption spectroscopy are MUPASS systems (MultiPass Absorption Spectroscopy Systems). They take advantage of using a specially designed cavity, which increases the optical path of infrared light in order to enhance sensitivity. Fully functioning MUPASS systems for detection of various gaseous species are emerging from research facilities and are expected to enter the commercialization phase in upcoming years. (https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-25-11-12743&id=366985)
- TDLAS (Tunable Diode Laser Absorption Spectroscopy) is a high-resolution infrared spectroscopic technique applied for gaseous samples. It combines regular absorption spectroscopy with tunable diode laser, which allows it to focus on one specific, isolated absorption line of particular species of interest. Light source is tunable laser diode (TDL), which can operate in broad spectral range (3 - 30 μm) and enables easy change of wavelength. Multi-pass cell and mirrors allow to increase optical path to hundreds of metres. Intensity of transmitted laser light is measured by a photodetector.
- ICOS (Integrated Cavity Output Spectroscopy) or CEAS (Cavity Enhanced Absorption Spectroscopy) – it is a laser spectroscopic technique, which uses a Fabry-Pérot external cavity, formed by two highly reflective mirrors, to increase path length. The laser beam in this technique is introduced to the cavity at a small angle (off-axis), which results in dense mode structure. Thanks to this system is less affected by instability of cavity and laser spectrum and also resonances of the cavity are avoided.
- FTIR (Fourier Transform Infrared) spectroscopy is a technique used to obtain either absorption or emission spectra of samples in various states. It utilises broadband thermal infrared light source, which shines onto a sample via an interferometer and then onto a detector. By Fourier transform algorithm, a very detailed broadband spectra of the sample is calculated as a result. This technique enables analysis of numerous gases at once and is commercially available in both laboratory and industrial devices. Fourier transform spectrometers were developed using MCT detectors.

New methods are emerging as well, e.g. using **optical frequency combs** in mid-IR to perform spectroscopy at much broader spectrum. Broad spectral response of MCT detectors combined with high detectivity is a great advantage in such equipment.

Environmental protection

Gas analyzers using above mentioned techniques are becoming increasingly compact, stable and user friendly, which helps find their way into application of constant emission monitoring. Data from such surveys can be used for better understanding of climate change and atmospheric processes, creating a map of emissions from natural and human-made sources, as well as active leak detection of hazardous components or greenhouse gases. Such analyzers are a crucial part in achieving control of atmospheric emissions and therefore enabling active protection of Earth’s atmosphere and its climate.

This application requires the devices to be reliable, sensitive and fast-responding. Spectroscopic techniques in connection with high sensitivity and speed of response of MCT detectors fulfill those requirements.

Examples of portable devices perfectly suited for greenhouse gases monitoring on-site utilizing MCT detectors include:

- Gasmet GT5000 Terra FTIR Gas Analyzer: https://www.gasmet.com/products/category/portable-gas-analyzers/gt5000-terra/
- ARCoptix GASEX PORTA FTIR Gas Analyzer: http://www.arcoptix.com/Portable_FTIR_Gas.htm
- MIRO Analytical MGA (TDLAS-based) multi gas analyzers: https://miro-analytical.com/mga9-mga10/
- Emerson Rosemount Continuous Gas Analyzers (TDLAS-based): https://www.emerson.com/en-gb/catalog/automation/measurement-instrumentation/quantum-cascade-laser-analyzers/rosemount-ct5400-continuous-gas-analyzer-en-gb
- ABB LGR-ICOS GLA laser analyzers:https://new.abb.com/products/measurement-products/analytical/laser-gas-analyzers/laser-analyzers/lgr-icos-portable-analyzers
- Aeris Technologies MIRA Pico gas analyzers (TDLAS-based): https://aerissensors.com/pico-series/
- Picarro Gas Concentration Analyzers (CRDS-based): https://www.picarro.com/products/gas_concentration_analyzers

Semiconductor industry

MCT detectors are perfectly suited for control of infrared light sourced from CO2 lasers. While for some applications of these lasers only basic detection is needed, MCT detectors allow for very precise measurements required sometimes, also for pulsed CO2 laser light.

A specific example of such application is precise, multi-aspect control of pulsed CO2 laser light used in EUV (Extreme UltraViolet) lithography machines. The latter are manufactured by Dutch company ASML, with CO2 laser modules supplied by German company TRUMPF Lasersystems for Semiconductor Manufacturing. Additional laser beam alignment systems are supplied to ASML by German company Hensoldt Optronics.

MCT detectors are a vital part of the laser modules and alignment systems. They have numerous critical roles throughout the laser light delivery chain, ranging from power measurement and beam alignment, up to exact beam and pulse shaping. They have been chosen as MCT is the only technology combining high detectivity with sufficiently fast response to be able to measure ultrashort laser pulses emitted at frequency of 10s of kHz.

The CO2 laser light is used to hit tin droplets, which then emit EUV light. EUV lithography is a state-of-the-art technology used in semiconductor manufacturing, namely electronic chips for e.g. processors, allowing ever further miniaturisation of consumer and professional electronics and enhancing the efficiency of the process. There is currently no possibility nor plans to modify the technology chain to not include CO2 laser light, and therefore to not use MCT detectors.

With ever growing demand for semiconductors worldwide, it is absolutely vital to ensure stability of the supply chain for EUV machines.

Infrared photodetectors

The key components of most IR systems are infrared detectors that convert the invisible radiation flux into easily measurable signals, typically electrical ones. The devices are characterized by a variety of parameters. The most important is the detectivity, which is the normalized signal to noise ratio and its spectral and time response.

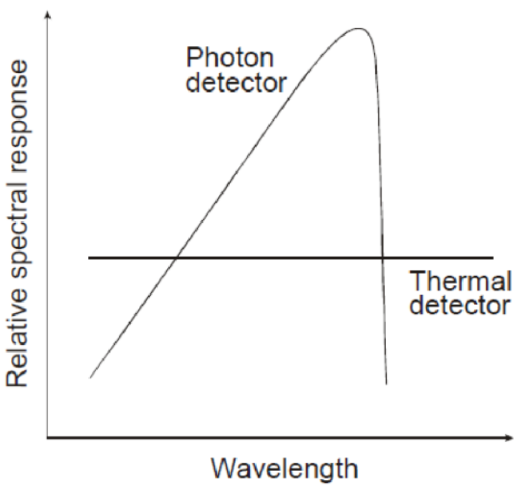
Detectors of optical radiation are usually categorized in one of two groups: thermal detectors and photon detectors (photodetectors).

Thermal detectors sense the heat generated by the absorbed radiation, so their operation is a two-step process: the conversion of radiation energy into heat, followed by the conversion of heat energy into the energy of an electrical signal. The signal does not depend upon the photonic nature of the incident radiation but upon the radiant power, and is generally wavelength-independent.

Being unselective, they can be used over an extremely wide range of the electromagnetic spectrum, from X-rays to ultra-violet, visible, IR, and microwaves. The room temperature operation of thermal detectors makes them lightweight, rugged, reliable and convenient to use. However, thermal detectors are characterized by moderate sensitivities and suffer from a slow response which prevents their use in demanding applications. Neither sensitivity nor speed of response can be improved significantly with cooling.

The operation of photodetectors is based on optical generation of charge carriers in semiconductor absorbers followed by a collection of the carriers at contacts. This makes it possible to achieve both high sensitivity and a fast response. Comparison of relative spectral response for thermal and photodetectors was shown on Figure 2.

Figure 2 – Relative spectral response for a photon and thermal detector



Photodetectors are traditionally categorized into photoconductive, photovoltaic, photoelectromagnetic, and other types depending on their design and the principle by which optically generated carriers are sensed.

The ultimate sensitivity of any type of infrared photodetectors is determined by the ratio of absorption coefficient to the thermal generation rate of charge carries [3]. Cooling is a natural and efficient way to suppress thermal generations. Recent considerations of the photodetector operation mechanisms suggest that the thermal generation can be suppressed in HOT photodetectors by means other than cooling, such that near-perfect detection can be achieved at ambient temperatures.

The direct band gap narrow gap semiconductors are the best materials for the HOT photodetectors. The II-VI, III-V and IV-VI compounds have been the material systems used in practice. They include fixed band gap binary alloys, tunable band gap ternary semiconductors, and band gap engineered superlattice materials. The binary compounds can be used for applications that require optimum performance at the spectral range corresponding to band gap of the material. Availability of binary compound is very limited, especially in the long wavelength (8-14 μm) (LWIR) range of IR spectrum. Therefore, the use of tunable band gap ternary and quaternary is necessary for many applications.

The variable band gap $Hg_{1-x}Cd_xTe$ (also called in short HgCdTe or MCT) has been undeniably the champion among the large variety of material systems [12]. Three key features condition its position:

- Wide band gap tunability by composition changes with a weak dependence of HgCdTe lattice constant on composition. It allows for growth of defect-free complex semiconductor heterostructures consisting of different composition layers which are necessary to optimize operation of the IR detectors at any wavelength within an extremely wide spectral range of 1 to 30 μm and temperatures 60 to 300 K. This also facilitates fabrication of multicolour and avalanche photodiodes.
- Favourable inherent charge carriers generation-recombination mechanisms, especially a very low rate of the Shockley-Read (SR) processes, leading to the best Signal-to Noise (S/N) performance [3][4].
- Favourable charge carriers transport properties which ensures an efficient and fast collection of photogenerated charge carriers and results in a high responsivity and fast response of HgCdTe-based devices.
- Recent ground-breaking works [46] have demonstrated further great increases in the detectivity of MCT detectors operating at near-room temperatures due to the unique properties of the material.

a. List of relevant categories: (mark more than one where applicable)

☐ 1	☐ 7
☐ 2	☐ 8
☐ 3	**X** 9
☐ 4	☐ 10
☐ 5	☐ 11
☐ 6	

b. Please specify if application is in use in other categories to which the exemption request does not refer:

cat. 8 - Medical Devices

c. Please specify for equipment of category 8 and 9:

The requested exemption will be applied in

X monitoring and control instruments in industry

X in-vitro diagnostics

X other medical devices or other monitoring and control instruments than those in industry

This application covers only Cat 9 (monitoring and control instruments in industry), as applications for Cat 8 (medical devices, including used in in vitro diagnostics) have already been submitted to the EC.

2. Which of the six substances is in use in the application/product?

(Indicate more than one where applicable)

☐ Pb **X** Cd **X** Hg ☐ Cr-VI ☐ PBB ☐ PBDE

3. Function of the substance: **Mercury and Cadmium are the basic components of mercury cadmium telluride (HgCdTe), the unique variable band gap semiconductor used for infrared (IR) photodetectors.**

4. Content of substance in homogeneous material (%weight):

Cadmium and Mercury are components of mercury cadmium telluride (MCT or HgCdTe), which is deposited on top of the Gallium Arsenide surface, creating infrared detector chip. Typical MCT layer has only thickness.

Concentration of mercury within a typical infrared detector single element chip - ~0,7% of chip weight.

Concentration of cadmium within a typical infrared detector single element chip - ~0,5% of chip weight.

5. Amount of substance entering the EU market annually through application for which the exemption is requested: **Mercury - 0,6g, Cadmium - 0,5g**

Please supply information and calculations to support stated figure.

No accurate data is available. It is estimated that yearly global production of MCT detectors for commercial application is around 20.000 pcs/year. Weight of a single pixel detector chip is around 0,005 g ($5*10^{-3}$g). Typical detector comprise 0,0000314g ($3,14*10^{-5}$g) of mercury and 0,0000235g ($2,35*10^{-5}$g) of cadmium.

Therefore the total global amount per year of mercury in MCT detectors is around 0,6g, while cadmium - 0,5g.

6. Name of material/component: **Infrared detector chip made of mercury-cadmium telluride**

7. Environmental Assessment:

LCA: ☐ Yes

X No

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

The two RoHS-regulated substances, Mercury and Cadmium, are the basic components of Mercury Cadmium Telluride (HgCdTe), the unique variable band gap semiconductor used for fabrication of infrared (IR) photodetectors.

(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

Mercury and Cadmium are the basic components of the variable band gap $Hg_{1-x}Cd_xTe$ alloy semiconductor which is the best material for infrared photodetectors [12]. Three key features condition its position:

- Wide band gap tunability by composition changes with a weak dependence of HgCdTe lattice constant on composition. It allows for growth of defect-free complex semiconductor heterostructures consisting of different composition layers which are necessary to optimize operation of the IR detectors at any wavelength within an extremely wide spectral range of 1 to 30 micrometers and temperatures 60 to 300 K. This also facilitates fabrication of multicolour and avalanche photodiodes.

- Favourable inherent charge carriers generation and recombination mechanisms leading to the best Signal-to Noise (S/N) performance.
- Favourable charge carriers transport properties which ensures an efficient and fast collection of photogenerated charge carriers and results in a high responsivity and fast response of HgCdTe-based devices.

The present state of art of HgCdTe photodiodes is described by the Lee *et al* [46] ultimate photodiode performance metric, the Law 19, an updated version of the previous Rule 07 [13] metric. It reflects the current advances in MCT detectors and their unparalleled performance.

5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

Mid-IR sensors, as professional laboratory equipment, are disposed of in a controlled system.

2) Please indicate where relevant:

X Article is collected and sent without dismantling for recycling

☐ Article is collected and completely refurbished for reuse

☐ Article is collected and dismantled:

  ☐ The following parts are refurbished for use as spare parts:

  ☐ The following parts are subsequently recycled:

☐ Article cannot be recycled and is therefore:

  ☐ Sent for energy return

  ☐ Landfilled

3) Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:

☐ In articles which are refurbished

X In articles which are recycled — Mercury - 0,6g, Cadmium - 0,5g

☐ In articles which are sent for energy return

☐ In articles which are landfilled

6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

The III–V semiconductors are alternatives for the use of RoHS regulated substances in fabrication of the infrared photodetectors [14-15]. InSb and InAs were the first III-V compounds discovered in the 1950s and used for photodetectors with the long cut-off wavelength of ~5.5 and ~3.2 μm, respectively at 77 K. The materials are characterized by a dark current much larger compared to that of HgCdTe of the same band gap. This is presumably associated with the Shockley-Read (SR) thermal generation. It is interesting to note that SR generation in InSb value has not been improved through the last 50 years. The use of the InSb and InAs is limited by the fixed cut-off wavelength of the materials. InGaAs and InAsSb are the variable band gap alloys, whose long cut-off wavelength can be tuned by changing the composition in the range from ~1 to ~ 3.4 and ~3.4 to ~20 um, respectively. The InAsSb alloys are characterized by the SR recombination time of ~400 ns similar to that of InSb, several orders of magnitude shorter compared to HgCdTe. The longest SRH-value for III-V materials equal to ~200 μs was found for SWIR lattice-matched epitaxial InGaAs ternary alloy on InP substrate, with cut-off wavelength of 1.7 μm [15].

The SR generation of the dark current occurs mostly in the depletion region of photodiodes. Therefore, the SR related dark current can be suppressed to a large degree by the use of the devices with neutral narrow band gap absorber. This can be achieved by the use of devices free of depletion layer such as such as the photoconductors or photoelectromagnetic devices consisting only of an absorber layer, and the three layers minority carrier photoconductors e.g. nBn [14-19]. Another solution is photodiodes with a wide gap unipolar barriers in which depletion layer is located in the wide gap materials where SR processes are highly suppressed. The barriers also block carriers thermally generated outside the absorber layer. The dark current in such devices is only the diffusion current generated in the neutral absorber by the less intensive SR, Auger, radiative and other mechanisms which highly improve the performance. The solutions do not prevent SR dark current generation in the narrow gap absorbers which limits the performance of the devices.

The last two decades have brought rapid development of detectors based on artificial superlattice semiconductors, initially the InAs/GaSb [20-24] and then InAs/InAsSb [14,15,25-27]. Theoretical consideration have promised better performance of the SL-based IR photodetectors compared to the HgCdTe counterparts, mostly due to the highly suppressed Auger thermal generation [20-21]. Actually, the dark current in the SL devices appeared to be dominated by a large SR generation rate. The more successful are Ga-free InA/InAsSb SL devices due to reduced SR generation [25-29]. As in the case of InAsSb alloy detectors, sophisticated detector architecture is a must to prevent the formation of a spatial charge in a narrow-gap absorber, where the SR generation could be very large. Another source of excessive dark current are dislocations due to mismatches between the substrates and different regions of the detector heterostructure. An additional issue is a short diffusion length in the MWIR and LWIR absorber which reduces the responsivity of the SL devices. The problem can be solved in cascade detectors with stacked multiple photovoltaic cells connected in series [30].

The potential benefits of new technologies have not been fully achieved in practice. It should be noted that SR generation does not have fundamental nature so the performance of the SL device can be improved by refinement of the material growth technology leading to reduction of defects in the heterostructures.

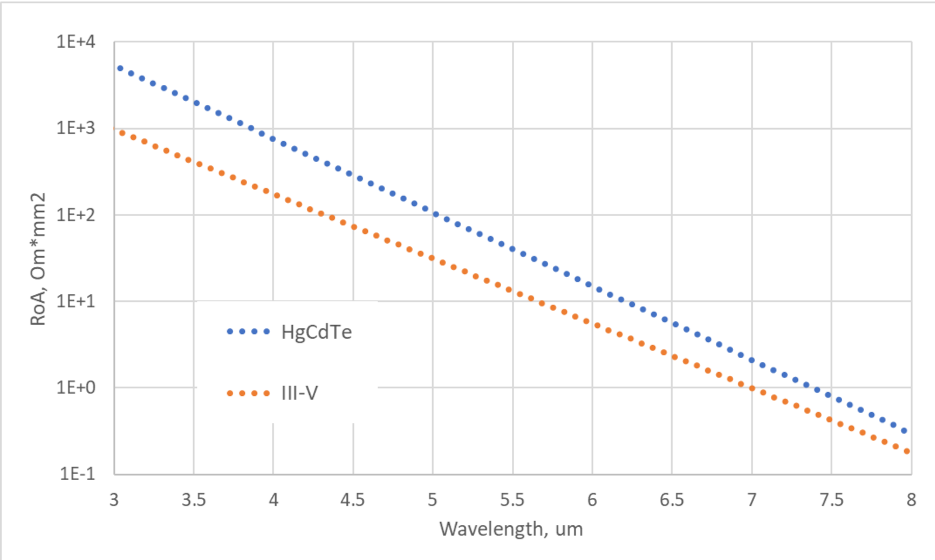
The III-V semiconductors also have significant disadvantages that hinder their widespread use:

- The lack of variable band gap alloys with a composition-independent lattice constant, which makes the fabrication of heterostructure devices very difficult.
- No universal matched substrates exist.
- Very complex crystal defect structure
- Large concentration of uncontrolled native and foreign dopants which results in unfavourable charge carriers generation and recombination mechanisms that reduce the Signal-to Noise (S/N) performance.

The bottom line- the technology of the III-V based RoHS-compliant devices is steadily progressing, but HgCdTe remains the material of choice for demanding applications [12,15,46].

(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

Figure 3 – Comparison of trend lines MCT (HgCdTe) and III-V materials at 230K (logarithmic scale), internal data VIGO Photonics.



Despites years of development there are no commercially available III-V detectors that would match the performance levels of MCT detectors. Performance of III-V detectors is still significantly lower than mercury-cadmium sensors – even up to order of magnitude (MCT detectors are 10x better than III-V detectors at some wavelengths).

7. Proposed actions to develop possible substitutes

(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

For many years, Intensive efforts have been underway for several decades to replace HgCdTe [14].

Theoretical analyses, literature studies and results obtained so far indicate the possibility of replacement of HgCdTe with the substitutes. Until now, the growth of complex heterostructures for the short, middle and long-wavelength detectors on GaAs substrates has been mastered.

This allows the production of detectors monolithically integrated with immersion microlenses, increasing sensitivity of the device by an order of magnitude. The most important results have been the development of uncooled and Peltier cooled devices [11, 31-43]:

- Short-wavelength MOCVD grown InGaAs photodiodes with cut-off wavelength from 1.7 to ~2.8 μm with detectivity ~2 x less than for HgCdTe devices
- MBE-grown InAsSb middle-wavelength photodiodes from 3.4 μm to 6 μm cut-off wavelength with detectivities ~3x less than for HgCdTe devices. The devices have already found some practical applications in less demanding chemical analyzers.
- Long (>10.6 μm) photoconductors based on MBE grown InAs/InAsSb superlattices with detectivities close to those of HgCdTe. The use of this device is limited, but the result proofs the feasibility of other types of the high quality long wavelength devices.
- Demonstration of cascade photodiodes with cutoff > 10 μm.

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

Establishment of substitute to the RoHS regulated substances would require:

- Improved design of the InAs/InAsSb detector heterostructures taking into account unavoidable limitations of the MBE and MOCVD epitaxial techniques
- Refinement of the growth procedures to reduce concentration of residual uncontrolled dopants, SR centers and density of dislocations in the the InAs/InAsSb SL-based detector heterostructures
- Growth and characterization of the heterostructures for several types of photodetectors.
- Processing, packaging and characterization of the several types of photodetectors for medical applications
- Iterative corrections of the design and growth procedures of detector heterostructures.
- Development of fast and sensitive devices with the use of plasmonic enhanced absorption of IR radiation

The abovementioned stages require a lot of effort in development and refinement of epitaxial growth techniques – where actual results are visible in nanoscale and are quite difficult to be measured. The applicant estimates that it would take another 5-7 years to introduce new type of III-V detectors with detectivity and reliability levels of MCT.

8. Justification according to Article 5(1)(a):

(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)? **No**

☐ Authorisation

☐ SVHC

☐ Candidate list

☐ Proposal inclusion Annex XIV

☐ Annex XIV

☐ Restriction

☐ Annex XVII

☐ Registry of intentions

☐ Registration

Although Mercury and Cadmium are listed in the Annex XVII, none of the entries currently listed under REACH apply to Mercury Cadmium Telluride (MCT) detectors.

2) Provide REACH-relevant information received through the supply chain.

Name of document: **N/A**

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?

X Yes. Consequences? **Elimination of MCT IR detectors would lead to significant deterioration of the accuracy of measurement and control devices.**

☐ No. Justification:

2. Can the substance named under 4.(A)1 be substituted?

☐ Yes.

☐ Design changes:

☐ Other materials:

☐ Other substance: Only for less demanding applications.

X No.

Justification: **There has not been yet any reliable substitutes for MCT detectors, offering comparable levels of detectivity at room temperature in the MWIR and LWIR IR spectrum.**

3. Give details on the reliability of substitutes (technical data + information):

See point 6B.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to

    1) Environmental impacts:

One of the most important applications for MCT infrared detectors is environmental monitoring. Infrared sensors (eg. laser spectroscopy or FTIR spectroscopy) are commonly used to monitor the quality of air and water, detect hazardous substances or greenhouse gases. Such analyzers play a crucial part in achieving control of atmospheric emissions and therefore enabling active protection of Earth's atmosphere and its climate. Withdrawal of MCT detectors would deteriorate the precision and sensitivity of the measurement and control instruments used for environmental monitoring and therefore actually lower the level of protection against emitters of hazardous substances or greenhouse gases.

    2) Health impacts:

    3) Consumer safety impacts:

Ad 2) and 3)

There is no direct exposure of cadmium or mercury on users of control and monitoring equipment using infrared detectors. Both cadmium and mercury are bound by covalent bonds within the semiconductor material. Mercury cadmium telluride material is then itself hermetically sealed during packaging. It is highly unlikely that a detector is handled, mechanically treated or otherwise modified by any user in such a way that cadmium or mercury could be released.

Also exposure to cadmium or mercury from infrared detectors released to the environment as a consequence of end-of-life or recycling operations is highly unlikely due to very small amount of these substances introduced to the market annually in infrared detectors (less than 1g annually).

⇨ Do impacts of substitution outweigh benefits thereof?

Please provide third-party verified assessment on this:

(C) Availability of substitutes:

a) Describe supply sources for substitutes: **N/A**

b) Have you encountered problems with the availability? Describe: **N/A**

c) Do you consider the price of the substitute to be a problem for the availability?

☐ Yes **X** No

d) What conditions need to be fulfilled to ensure the availability? **N/A**

(D) Socio-economic impact of substitution:

⇨ What kind of economic effects do you consider related to substitution?

☐ Increase in direct production costs

☐ Increase in fixed costs

☐ Increase in overhead

X Possible social impacts within the EU

Negative impacts on European Union economic growth

According to Photonics21 market report [44] European industry is already among the global leaders in the healthcare market, which is growing with double-digits. The total market volume of the segment in 2015 was €33.8 billion. Photonics for Healthcare is assumed to reach around €50 billion worldwide by 2021. Accordingly, it is not only one of the largest markets among photonics, but also one of the more rapidly expanding sectors. With its rich innovation landscape formed by traditional companies, start-ups, universities and research institutions, Europe has a unique opportunity to secure a prominent role and lead the corresponding markets if the challenges are met accordingly in the next few years.

EU has currently leading position in the market of MCT detectors production for commercial (medical, monitoring and control instruments), with more than 50% of the market share, which is also growing very fast (>10% growth in recent years). Moreover, MCT detectors are critical components for many EU companies producing measurement and control equipment for many applications (industrial, medical, scientific, etc.). There is no accurate data on the global market for MCT detectors in commercial applications. It is estimated that its value is around 30-50 million EUR. However, the value of the market of measurement and control instruments using MCT detectors is at least 10x larger.

Withdrawal of MCT detectors would undermine the position of EU companies in the global market, especially in comparison to companies from other regions, where using MCT detectors is not prohibited.

Negative impacts on the semiconductor industry

MCT detectors are key components of the most advanced EUV photolitography machines manufactured by ASML. Withdrawal of MCT detectors would significantly impact the performance of EUV systems, which would undermine the EU position in the market of semiconductor equipment, as well as it could have a detrimental effect on the overall global semiconductor market.

☐ Possible social impacts external to the EU

Social impacts external to the EU will be significantly less severe as there is no prohibition of use of MCT detectors in medical diagnostics instruments outside of the EU.

☐ Other:

⇨ Provide sufficient evidence (third-party verified) to support your statement:

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

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10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

The information referring to specific products and customers using MCT detectors should be regarded as proprietary information (marked grey on p. 7-8, 18).