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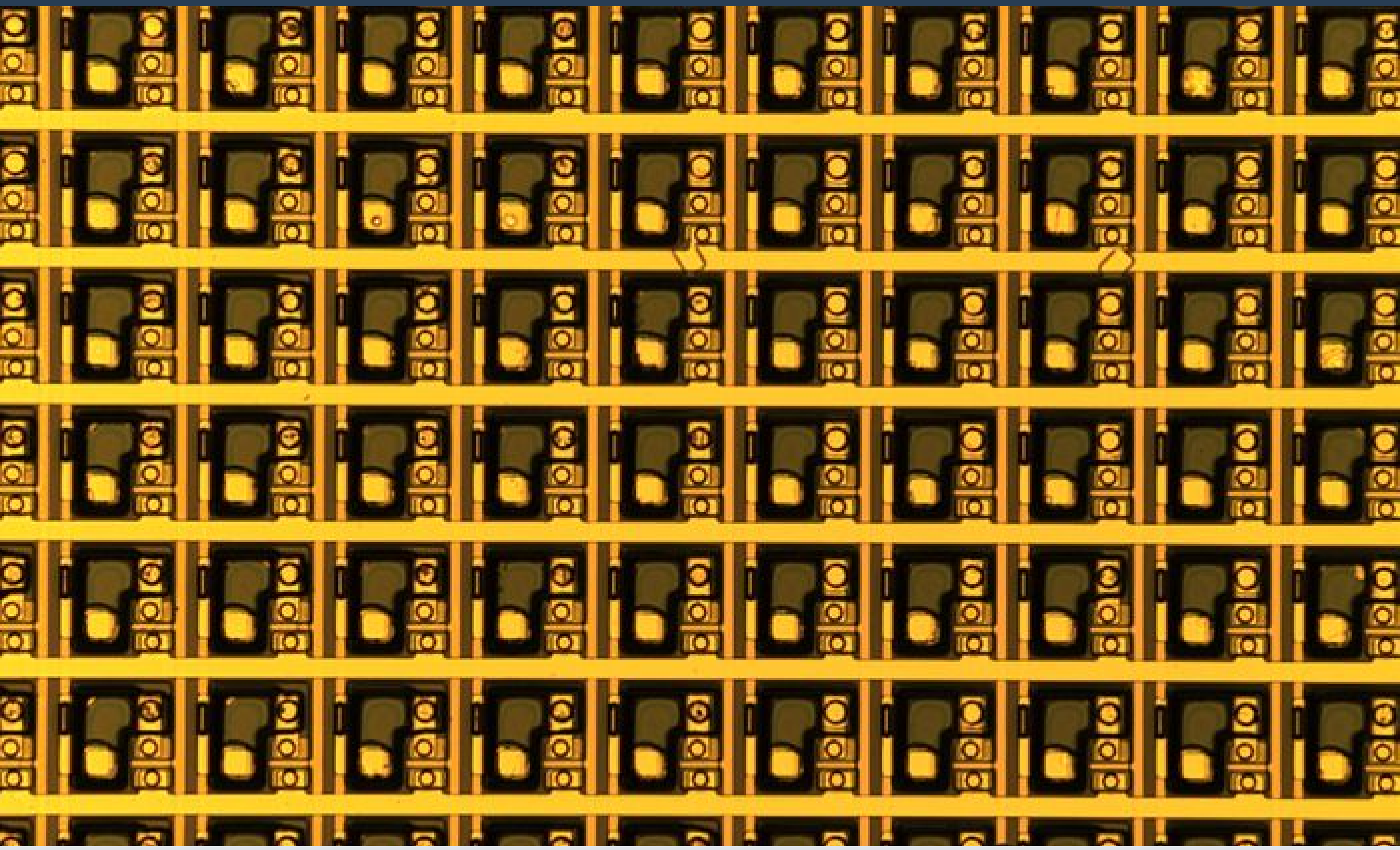
IndiPIX™: Paving the way towards compact, portable, and cost-effective mid-wave infrared systems imaging systems

Technology that opens new applications in gas imaging, and domestic and light industrial safety

Reference: IndiPIX



University of Glasgow's 64x64 pixel IndiPIX MWIR imager under a microscope

IP Status

Patented, Patent application submitted

Seeking

Development partner, Commercial partner, Licensing

Background

Market drivers: towards a compact, portable, low-cost device that unlocks new applications

In today's market, there is a need for medium wavelength infrared sensors and cameras that can be used for stand-off gas imaging and leak detection, energy and environmental monitoring, and domestic and light industrial safety, among others.

Existing materials are problematic

Traditionally, MWIR cameras require cryogenic cooling systems and specialist substrates such as gallium antimonide (GaSb) that are difficult to source and expensive. These materials also provide a somewhat impractical platform on which to fabricate devices as they require a hybridized approach with CMOS silicon readout chips using flip-chip bonding.

Mercury cadmium telluride (MCT), one of the most commonly used compounds in MWIR imagers, is currently classified as a toxic element and is a restricted substance. In the near future, the element may be banned from use in manufacturing due to health and safety concerns.

Among semiconductors, MCT also provides one of the weakest mercury telluride (HgTe) covalent bonds, resulting in poor bulk concentration and interface instabilities. Poor uniformity and yield are also common issues with the material.

Current MWIR devices are difficult to transport

Most MWIR cameras on the market weigh from 2.5 kg, making them heavy and difficult to transport. They require a mechanical refrigeration unit that also makes them too heavy to mount on small drones – an integration that would greatly benefit industrial users.

High cost of existing devices

Most existing MWIR imagers cost in the region of $35-150k due to their expensive fabrication process, materials, and components.

The technical challenges of developing mid-infrared imaging devices and how these have been met to date

To enable an imaging device, such as a focal plane array (FPA), each pixel needs to be read individually. At visible wavelengths, this is achieved through silicon photodiodes that are sensitive to visible wavelengths monolithically-integrated with silicon transistors.

High leakage currents

When fabricating transistors, the materials used for mid-wave IR detection, such as MCT and InSb have high leakage currents. As such, transistors made on these substrates are not suitable for pixel addressing.

Flip-chip bonding

To date, this technical challenge has been remedied by implementing the MWIR photodiodes and transistors for readout on two separate chips. The photodiodes are typically fabricated using InSb or MCT materials, with the readout integrated circuits (ROICs) being fabricated on complementary metal oxide semiconductor (CMOS) silicon wafers.

The wafers are then diced into chips, and subsequently flipped and connected to the InSb or MCT elements using conductive metal bumps in a technique known as flip-chip bonding. This practice has grown significantly in recent years and has become the standard process by which MWIR imagers are manufactured.

To make the bonds conductive metals such as indium are used. These are placed between the bond pads on the photodiode materials and those on the CMOS silicon wafers. As a soft metal, indium has a low melting point, high ductility and small yield stresses at cryogenic temperatures, making it a suitable bonding agent between the bond pads on the two materials.

Limitations of a hybridized approach

This hybridized approach does not, however, allow for wafer-level manufacturing. Moreover, with the pixel pitch of current MWIR imagers below 30 µm, the alignment of the flip-chipped bonded chips is critical, and misalignment can lead to reduced yield.

At the etching stage, potassium dichromate ($K_2Cr_2O_7$) is often used as an oxidizing agent. However, as with all hexavalent chromium compounds, it causes acute and chronic harm to health.

With flip-chip bonding, there are two major factors that lead to the fracture of InSb chips when under thermal shock. The first, is damage caused during fabrication, and the second is stress caused by thermal mismatch.

During fabrication, the space between the InSb chip and ROIC chip is filled with plastic colloid to provide support and reduce the impact of external strains on the indium bumps. However, the stress that is distributed on the indium bump joints is then concentrated and transferred to the InSb chip. As such, fracture often occurs when the InSb chip has been thinned to 10 µm due to the easy-cleavage properties of the material.

Operation of most commercially available MWIR cameras requires repeated cooling cycles. Prior to operation, when temperatures are rapidly reduced from ambient to cryogenic temperature, the coefficients of thermal expansion (CTE) are mismatched between the InSb chip and the silicon ROIC, which creates thermal strain and often causes a fracture.

To avoid failure due to strain from repeated thermal cycles, MWIR imagers require not only operation, but also storage at cryogenic temperatures.

An expensive process

Flip-chip bonding is also a costly process, partly because it does not allow for multiple imager batches to be processed concurrently. Also, due to their relative scarcities, the costs of InSb and MCT substrates are high. By comparison, 2-inch GaAs wafers sell for less than $60. The lower price of GaAs significantly reduces the cost barrier for MWIR imaging devices, enabling them to become more widespread.

Tech Overview

IndiPIX™ is a novel mid-wave infrared (MWIR) imager that offers indium antimonide (InSb) photodiodes on gallium arsenide (GaAs) transistors. It has the enormous potential to provide a lower cost, easier to fabricate, miniaturized alternative to existing MWIR imaging technologies. It achieves this by eliminating the need for both flip-chip bonding and cryogenic cooling, and by using lower-cost materials.

Such an imager could generate significant benefits in the petrochemical and oil and gas industries. Being able to remotely pinpoint and rapidly remediate gas leaks and plumes will help such facilities mitigate the risk of explosion, meet environmental regulations, and reduce product and economic loss. The imagers can be used as part of MWIR CCTV operations and be mounted on drones to detect leaks at remote locations.

The imaging of hydrocarbon gases such as methane, propane and butane can be used in industrial asset management to visualize leaks and plumes escaping from plant, storage wells, and landfill sites.

In domestic and light industrial environments, IndiPIX™ can be used to identify gas leaks of volatile organic compounds (VOC) in a practical and affordable way. A handheld device can be realized to easily determine the precise source of toxic pollutants and enable follow-up remediation measures.

The Technology

Monolithically-integrated GaAs transistors read each pixel individually, eliminating the need for a flip-chipped read-out integrated circuit. In turn, this reduces the manufacturing costs of the imager as several fabrication steps are eliminated. These materials have lower costs and are easier to source. Portability is also improved due to the camera's reduced weight.

The technology has been successfully demonstrated using a single active pixel, as well as 4x4 and 8x8 pixel arrays. The pixels have been extensively characterized using a laser source emitting at 4.57 µm and have presented excellent electro-optical response uniformity. They have also been characterized with sources matching the absorption lines of CO2 and butane, validating its use as a gas imager.

To further demonstrate the adaptability of the technology, we are working towards imaging various gases that strongly absorb mid-infrared wavelengths. We are also developing a 64x64 array, suitable for entering the market.

Key Features

IndiPIX™ is a MWIR imaging technology with the following unique characteristics that set it apart from traditional hybridized FPAs:

- An InSb photodiode is monolithically-integrated with a GaAs MESFET for pixel addressing, i.e., all processing takes place on a single piece of material.
- The material structure realizing the InSb photodiode is not grown on top of InSb or GaSb as in commercial MWIR imagers but on a cost-saving GaAs semi-insulating substrate, therefore the GaAs layers can be functionalized, implementing both the MESFET and the above InSb layer through a technique called molecular beam epitaxy (MBE).
- The monolithic integration of InSb photodiode and GaAs MESFET allows the fabrication of the IndiPIX™ imagers to be carried out on a wafer-scale, where several imagers can be processed in parallel until the fabrication process is complete.
- The only processes that take place after the wafer is split into individual dice are chip carrier mounting and wire bonding. In contrast, with a flipped-chip MWIR imager, there are multiple additional steps, such as indium ball formation, wafer alignment, bonding and wafer thinning.

Despite these differences between IndiPIX and hybridized MWIR FPAs, the technology still retains the key advantages of most MWIR imaging systems:

- It covers the entire MWIR spectral range and can image long distances due to the high atmospheric transmission at MWIR wavelengths.
- The technology can identify several substances that have strong absorption in the MWIR. Essentially, IndiPIX™ can pave the way for an increased presence of MWIR imagers outside traditional industrial settings.

Benefits

Our technology addresses the shortcomings of the today's MWIR devices on the market and has the potential to unlock new marketplaces and applications.

1. IndiPIX™ technology has the potential to open up gas imaging systems to previously unreachable markets, where cost has a significant impact on the commercial availability of MWIR imagers.
2. Devices are fabricated using cost-saving GaAs substrates, eliminating the need for expensive InSb and MCT substrates. By contrast, GaAs is inexpensive, with a 2-inch wafer costing less than $60.
3. A monolithic approach eliminates the need for flip-chip bonding, allowing for wafer-scale fabrication rather than single die-processing.
4. There's no need for bulky cryogenic cooling systems, so the device is lighter and more compact, making it portable and suitable for mounting on drones.
5. The semiconductor fabrication process is more standardized and robust, so components are more affordable and easier to source compared to the expensive and inaccessible materials used in flip-chip

bonding.

6. Using antimonides on GaAs requires less regulation than the MCT materials currently used in existing devices. MCT in particular, is classified as a toxic element and is a REACH restricted substance, which may be banned from use in manufacturing in the future.
7. Unlike in flip-chip bonding, IndiPIX™ does not use hazardous potassium dichromate to etch into the InSb chip, making the fabrication process safer.

Applications

We foresee the technology being used extensively in the petrochemical and oil and gas industries. Gas leak and plume imaging is of particular interest in the wavelength range between 3 and 6 µm, a spectral region in which characteristic absorption lines of many gases lie.

The petrochemical industry is a major source of toxic pollutants, primarily complex polycyclic aromatic hydrocarbons (PAHs). These hydrocarbons are mutagenic and carcinogenic and have a negative impact on the environment and on human health. They are a major source of visual and aquatic pollution because of their toxicity.

According to the International Energy Agency (IEA), oil and gas operations worldwide emitted just over 70 Mt of methane into the atmosphere in 2020, which is comparable to the total energy-related CO2 emissions of the European Union given that methane is a more potent greenhouse gas (GHG) than CO2.

Rapid identification and repair of hydrocarbon leaks has several advantages for the oil and gas industry: it helps them to meet environmental regulations on emissions, reduces product loss and related economic loss, and increases safety by addressing leaks before they become an explosion risk.

IndiPIX™ can be used as part of CCTV operations at petrochemical and oil and gas facilities, enabling automated monitoring. Likewise, mounting low-mass IndiPIX™ imagers on drones can provide close-up validation of detected leaks without endangering personnel.

The imaging of hydrocarbon gases such as methane, propane and butane is also relevant to industrial asset management and has potential for applications, such as the visualization of leaks and plumes escaping from plant, storage wells, and landfill sites.

IndiPIX™ has potential to be used in both domestic and light industrial environments to identify gas leaks of volatile organic compounds (VOC) in a practical and affordable way. A hand-held device could be realized to easily determine the precise source of toxic pollutants and enable follow-up remediation measures.

Cameras using IndiPIX can visualize CO2, ensuring levels remain safe in homes. Concentrations of CO2 between 400-1,000 ppm (parts per million) are typical of indoor spaces with good air exchange. Levels from 1,000-5,000 ppm can cause drowsiness, headaches and nausea.

The team is also working to transfer the current monolithic technology pioneered by Glasgow's researchers to a wafer-level industrial manufacturing line, while exploring additional pixel functionalities such as avalanche detection.

Opportunity

Through the University of Glasgow's commercialisation unit, the Glasgow team invites discussion over licensing, collaborations, further R&D, investment, and other, similar opportunities.

The team is especially interested in discussions with manufacturers of CCTV and gas imaging and sensing technologies, and potential users including petrochemical facilities, oil and gas facilities, as well as .

In short, the team's door is open to anyone with an interest in employing the potentially disruptive IP to transform the gas imaging landscape, and in benefitting from the significant potential for commercial benefit to be obtained from so doing.

Patents

- US11056531B2
- EP3635785A1
- CN110709991A