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Technological Concepts and Applications for Uncooled MWIR Imagers

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Abstract

Uncooled MWIR imagers are not widely used until now, but offer great potential for various imaging scenarios. Fraunhofer IMS is therefore developing specialized imagers for the MWIR spectral range between 3 – 5 µm. In contrast to quarter-wavelength resonators, which are the established concept for LWIR optimized microbolometers, the integration of plasmonic metamaterial absorbers (PMA) realized by metal-insulator-metal absorbers (MIM) enables uncooled MWIR imaging. PMAs allow for the realization of narrowband MWIR imagers that may be a supplement to the classic broadband infrared imagers based on quarter-wavelength resonators. An overview of both approaches and their application-oriented advantages and disadvantages is given within this paper.

Keywords: uncooled thermal imaging, infrared focal plane array, IRFPA, microbolometer, LWIR, MWIR, plasmonic metamaterial absorbers, PMA, metal-insulator-metal absorbers, MIM

Introduction

Over the last few decades, cooled detectors based on HgCdTe, InSb and T2SL [1] have become established for visualizing the radiation of the mid wavelength infrared (MWIR) regime ranging from 3 µm to 5 µm. However, all these detector types require low operating temperatures of around 77 – 250 K [1, 2] and therefore a complex technical cooling equipment.

Against it, in the uncooled detector segment, microbolometers are well-established components for thermal imaging applications featuring benefits in all three costs, detector lifetime and power consumption as compared to their cooled counterparts. Since microbolometers are originally designed and, so far, only optimized for the long wavelength infrared (LWIR) regime ranging from 8 µm to 14 µm, Fraunhofer IMS develops uncooled thermal imagers based on microbolometers targeting the wavelength spectrum of the MWIR for high temperature and gas imaging applications.

In this regard, research at Fraunhofer IMS is being carried out on two different types of microbolometers featuring two concepts for absorbing the infrared radiation in order to tune the spectral range of choice to be absorbed along with its bandwidth.

Uncooled Thermal Imager

Uncooled thermal imagers are mainly realized by microbolometers, which are composed of an IR-sensitive and thermally insulated membrane that is electrically connected to a readout integrated circuit (ROIC).

The microbolometer array is sealed by a vacuum package to minimize the thermal conductance stemming from gas convection. The lid of the vacuum package provides an anti-reflective coating (ARC) to enhance the transmission characteristics for incoming IR radiation and is mounted by a solder frame to the substrate containing the ROIC. A getter material is coated at the inside of the housing to adsorb residual gas atoms and molecules for a further reduction of the inner pressure of the packaging.

MWIR Vacuum Packaging

Fraunhofer IMS's ARC for a vacuum package suited for the MWIR relies on a multilayer structure composed of silicon nitride (Si_3N_4) and silicon dioxide (SiO_2). Such multilayer structures can change the effective refractive index of optical media and allow for high transmission of the respective wavelength spectrum of interest.

The corresponding layer stack of silicon nitride (Si_3N_4) and silicon dioxide (SiO_2) was simulated as a multilayer ARC on both sides of a silicon substrate by using OpenFilters, an open-source software for designing and optimizing optical filters.

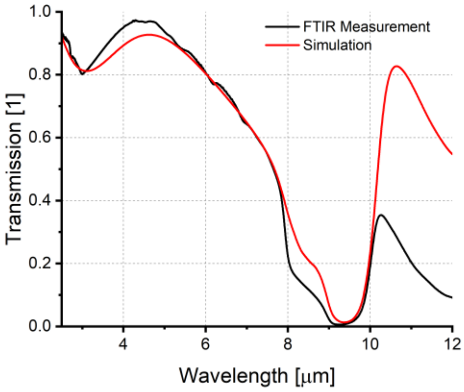

Figure 1: Simulated and measured transmission spectra of MWIR lid [3].

Based on these simulation results, a MWIR-transparent lid was fabricated by depositing Si_3N_4 and SiO_2 on both sides of the silicon substrate. The optical characterization of the lid was performed using Fourier transform infrared (FTIR) spectroscopy. Fig. 1 shows the simulated and measured transmission spectra for the MWIR lid.

A good agreement between simulation and experimental results can be observed in the MWIR target regime. Hence, by using a multilayer ARC, control and tuning of the transmission spectrum of the lid for the desired spectral range can be achieved.

However, the simulation overestimates transmission for wavelengths above 10 µm. This overestimated transmission stems from the used material data for Si_3N_4 [4], which match well with the optical properties of our fabricated Si_3N_4 in the MWIR, but do not provide any data for the optical extinction coefficient. The significant reduction in the transmission spectrum observed at about 9.3 µm is due to the high extinction coefficient of SiO_2 at this explicit wavelength.

All in all, a MWIR-optimized lid with a high transmission spectrum and a peak maximum at about 4.5 µm could be successfully fabricated.

Concepts for MWIR Absorbers

Within the field of microbolometer technology, two concepts have been established to adjust the absorption to the desired spectral range. The most prominent type is given by an absorber concept relying on a λ/4 arrangement between a reflecting and an absorbing layer. On the other hand, there are plasmonic metamaterial absorbers (PMA) based on a resonant coupling between the metamaterial structure and incident electromagnetic waves. A common type of PMAs are the so-called plasmonic metal-insulator-metal absorbers (MIM). While the quarter-wavelength resonator represents the standard design for commercial uncooled LWIR imagers, PMA-based microbolometers are still topic of current research [5].

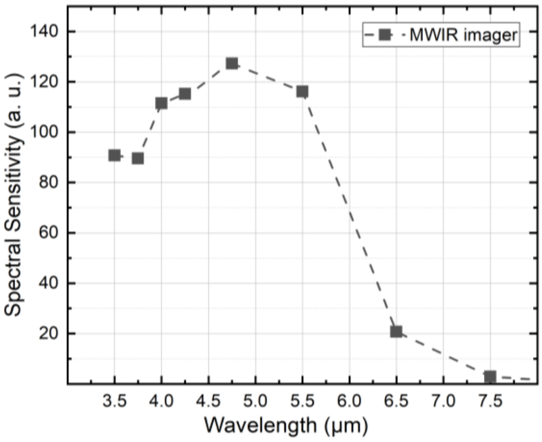

Figure 2: Measured spectral sensitivity of Fraunhofer IMS's uncooled MWIR imager [3].

Figure 2 shows the measured spectral sensitivities of Fraunhofer IMS's first uncooled MWIR demonstrator relying on a quarter-wavelength resonator. The maximum sensitivity ranges from 4 µm to 5.5 µm and correlates with the transmission spectrum of the lid of the vacuum package (compare Fig. 1). The corresponding observed broadband absorption characteristic arises from the quarter-wavelength resonator; its cut off for wavelengths above 6 µm as depicted in Fig. 2 stems from the transmission characteristics of our MWIR lid and the used camera lens.

A broadband absorption spectrum enables a higher temperature contrast within a scene due to a correspondingly large absorbed radiant power, making imagers based on quarter-wavelength resonators particularly suited for thermal imaging applications.

In contrast to this, the investigated PMAs are designed in a MIM stack configuration, featuring square-shaped top metal patches composed of AlSi as metal and variants of Ta_2O_5, Al_2O_3 and SiO_2 as framed dielectric. While the absorption characteristic of the quarter-wavelength resonator is determined by the optical distance between the reflector and absorber, the edge length of the metal patches and the chosen dielectric are decisive for the absorbed wavelength interval of the MIM PMAs.

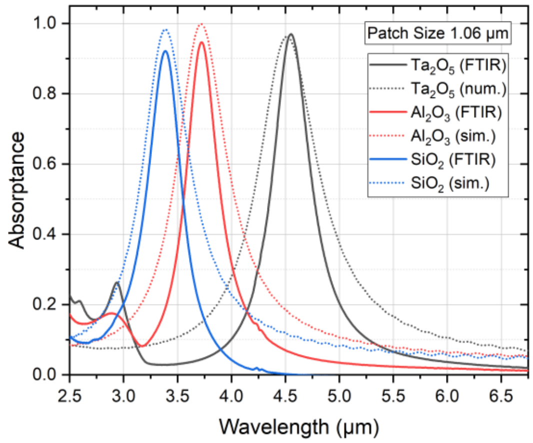

Figure 3: Simulated and measured absorption spectra of PMA absorbers [5].

Fig. 3 shows examples of three measured and simulated spectra of different MIM absorbers [5]. These MIM absorbers were processed as periodic test structures on a silicon wafer and evaluated using FTIR. Depending on the respective choice of dielectric, the absorption peak varies between 3 µm and 5 µm for a fixed edge length of the metal patches of 1.06 µm.

The MIM PMAs show a discrete absorption spectrum with a FWHM of approx. 0.5 µm for all materials investigated. Compared with the absorption characteristics of the MWIR imager based on a quarter-wavelength resonator, the absorption peaks are significantly narrower as expected. This means that a microbolometer equipped with MIM absorbers absorbs less radiant power, however, this can be assigned to a significantly more defined spectral range.

Applications for MWIR Imagers

While LWIR imagers are primarily optimized for the visualization of heat radiation close to room temperature, MWIR imagers are better suited for a high-contrast illustration of hot objects (400 °C and above).

Fig. 4 displays a burning candle in a tealight taken by Fraunhofer IMS's uncooled MWIR QVGA imager. The picture features a high image contrast in both the area of the flame and its surrounding gases, whereas the image corners, which are at room temperature, are effectively suppressed as expected. This image illustrates that broadband absorption using a quarter-wavelength resonator is well suited for imaging applications. However, such an image could be well supported by the use of MIM PMAs, for example to address individual absorption bands of gases for their specific detection.

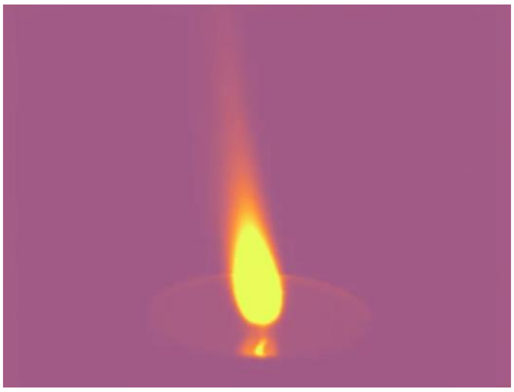

Figure 4: Image of a candle, taken with Fraunhofer IMS's uncooled QVGA-MWIR imager.

Summary and Outlook

While a first demonstrator of an uncooled MWIR imager based on a quarter-wavelength resonator has already been presented [3], the integration of MIM PMAs into proven microbolometer technology is still subject of current work [5]. Both technologies, individually and in combination, have the potential to perform either qualitative or quantitative monitoring and visualization tasks, for example in the detection of fires or gas leakages.

Literature

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