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Frequency up-conversion based single photon, mid-IR spectral imaging with 20% quantum efficiency

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Abstract: Spectral imaging of mid-infrared (mid-IR) light is emerging as a promising technology since important chemical compounds display unique and strong mid-IR spectral fingerprints. We demonstrate for detection a novel method including a field deployable imaging system with single photon sensitivity and 20% quantum efficiency in the 2.9-4.5 µm range.

Parametric frequency conversion has been one preferred technology for the generation of coherent emission at wavelengths, where lasers have lacked efficient performance, particularly in the UV and IR spectral range. Today many new light sources have emerged, including Quantum Cascade Lasers (QCL) covering most of the Mid-IR spectrum. However, low noise, sensitive, room temperature imaging systems and spectrometers lag behind.

A fundamental hurdle in Mid-IR detection is thermally emitted photons leading to unwanted dark current, thereby preventing single photon imaging and detection. In this work we exploit second order parametric up-conversion facilitating low noise detection of mid-IR light. Using a transparent nonlinear media, thus having very small emissivity, we avoid thermally generated noise in the conversion process. Frequency up-conversion of infrared images was first investigated in the 1960's [1]. However, very low efficiencies of for continuous wave systems have been prohibitive for practical applications.

We present an up-conversion system operating at room temperature, with a dark noise of only 0.2 photons/spatial element/second, which is a billion times below the dark noise level of cryogenically cooled InSb cameras. Single photon, mid-IR imaging is demonstrated as well as an image resolution of up to 200 x 100 spatial elements. The quantum efficiency is as high as 20% for continuous wave operation at 3µm for linearly polarized incoherent light. Furthermore, the up-conversion approach allows for multispectral imaging, and we present different images containing spectral information [2].

We consider the proposed method relevant for both existing and new mid-IR applications combining high sensitivity and spectral response, e.g. in gas analysis where fundamental band spectroscopy can be realized and for future medical diagnostics such as breath analysis [3].

References

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