# Fast Terahertz Imaging using a Quantum Cascade Amplifier up to 20,000 pps

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The drive to develop ever better imaging techniques at terahertz (THz) frequencies holds tremendous promise in advancing a diverse range of fields, including biomedicine, security sensing, quality control and spectroscopic mapping. Recently, a technique has been demonstrated which employs a quantum cascade laser (QCL) to act as a source and detector simultaneously, via the self-mixing (SM) effect. Radiation reflected back from a target is coupled into the laser cavity, interfering with the intra-cavity field, and producing measureable perturbations in bias voltage containing spatially dependent information about the target. However, current limitations exist in the amount of radiation capable of being back-coupled to the sub-wavelength sized laser facet, as well as the speed at which resolved information can be recorded.

In this work, we present a novel and powerful approach to SM imaging using a 2.9 THz single plasmon QCL, converted into a quantum cascade amplifier (QCA), and operated in pulsed mode at 20 kHz. This was achieved via the use of an anti-reflection coatedsilicon lens mounted on the laser facet to fully suppress lasing action. Radiation was collected and focused via off-axis parabolic mirrors onto a target, with resulting reflections coupled back into the QCA. The induced voltage perturbations were fed into a lock-in amplifier after being differentially amplified with respect to a pulsed reference voltage of equal frequency to the QCA drive current.

The use of an anti-reflection coated lens presents numerous advantages over a standard SM setup. Not only does the impedance matching of the lens increase the power output of the laser, but a much higher proportion of returning radiation is focused directly into the facet. Coupled with the reduction of the reflectivity of the Si/air interface to <5%, these considerations act in tandem to dramatically increase the amplitude of measureable signal. More significantly however, due to the suppression of lasing, the QCA can be biased at the point of maximum alignment, rather than at threshold, which unlocks the entire gain of the structure. The resulting signal to noise (S/N) at 6% duty cycle was demonstrated to be 55 dB, up to 6 times that of reported values of systems operating at threshold, and was shown to be ~1.4 times greater still at 10% duty cycle, the limit of the particular biasing setup employed.

The increase in signal allowed continuous scanning of the target object, dramatically increasing the acquisition time compared to discrete step scanning methods, without sacrificing image quality. A 0.7 mm aperture was also included in the focal point of the second parabolic mirror to increase the resolution of the system, which was estimated to be ~300 µm, obtained through knife edge tests. The sensitivity was high enough to enable acquisition of 20,000 points per second (pps), with a gold coin as the target. In conclusion, this fast THz imaging system we developed represents significant progress in the field of THz sensing, where potential applicability is extremely far-reaching.