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Detection of coherent single-pass amplification of sub-Terahertz acoustic waves

C. L. Poyser, A. V. Akimov, R. P. Campion, A. J. Kent

Motivation: SASER superlattice

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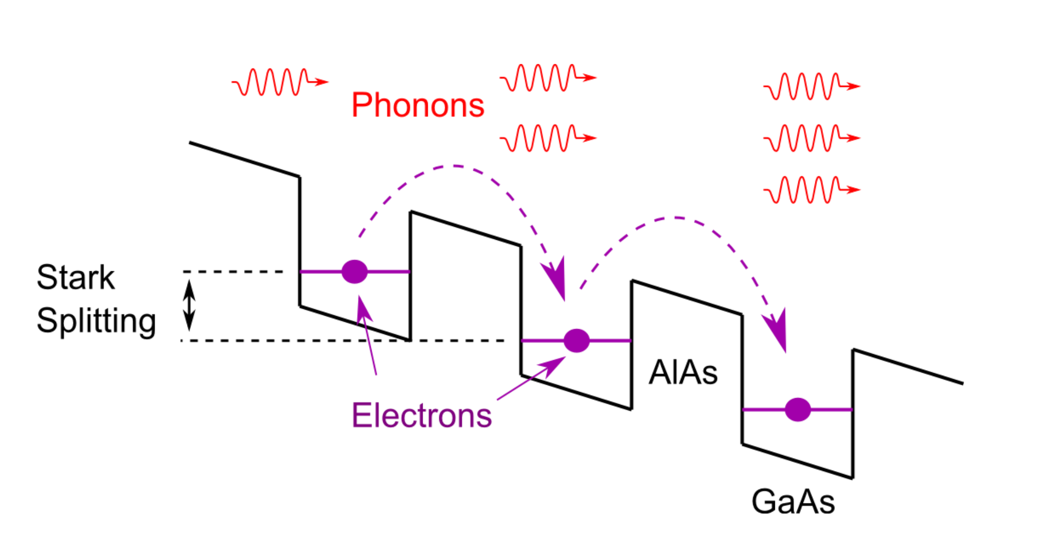


When placed under a sufficiently large electrical bias electrons in a superlattice become isolated in separate quantum wells.

For certain values of Stark splitting THz phonon amplification can occur creating a phonon LASER, a SASER.

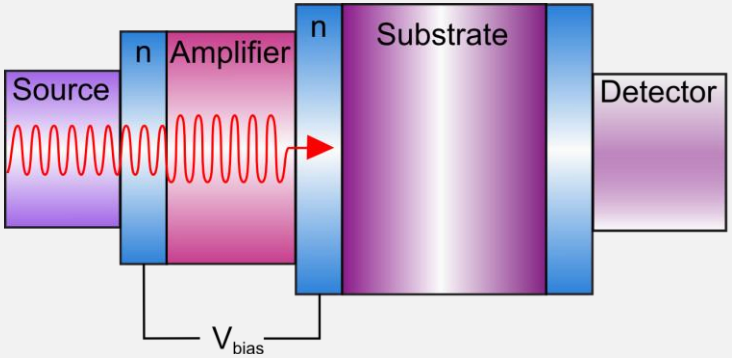
This was previously demonstrated using an incoherent detection method.

[Beardsley et al., New J. Phys. **13,** 073007, (2011)]
[Maryam et al., Nat. Commun., **4**, 2184, (2013)]

Motivation

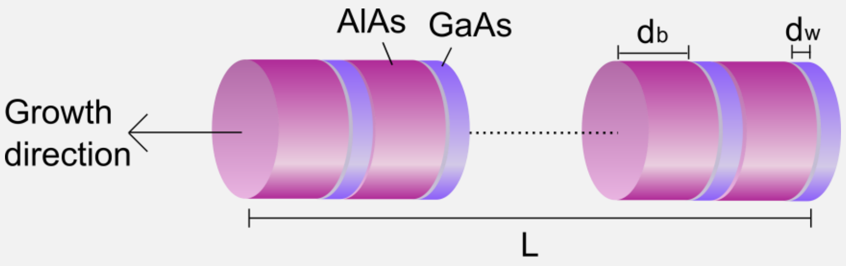
The aim of this work was to investigate coherent amplification in a saser structure, to achieve this we:

- developed a structure to integrate the generation and amplification of sub-THz sound with coherent detection of high sensitivity and temporal resolution.
- applied this technique to a single-pass phonon amplification structure.

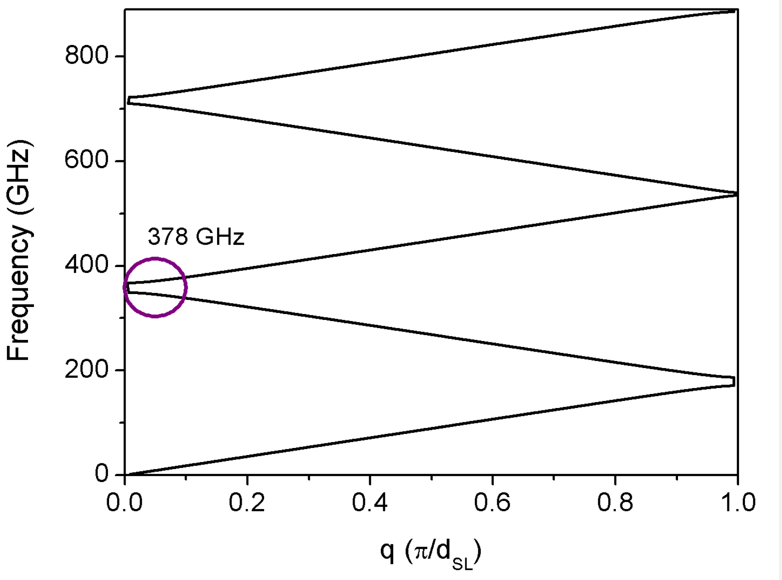


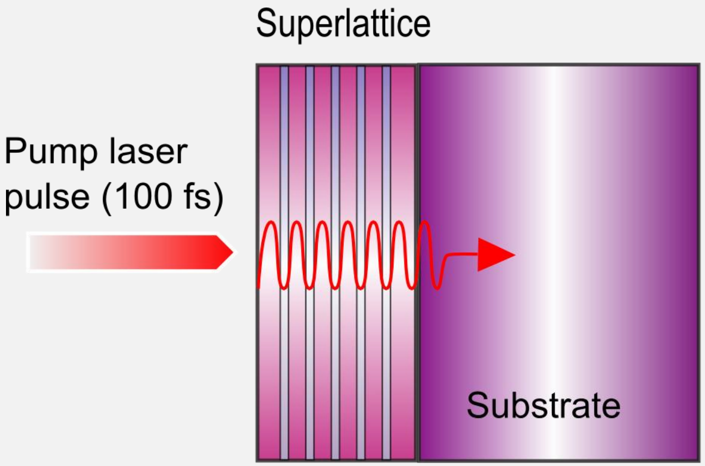
Semiconductor superlattices
Acoustic generation

A superlattice (SL) consists of alternating layers of different semiconductors



$d_{SL} = d_b + d_w$



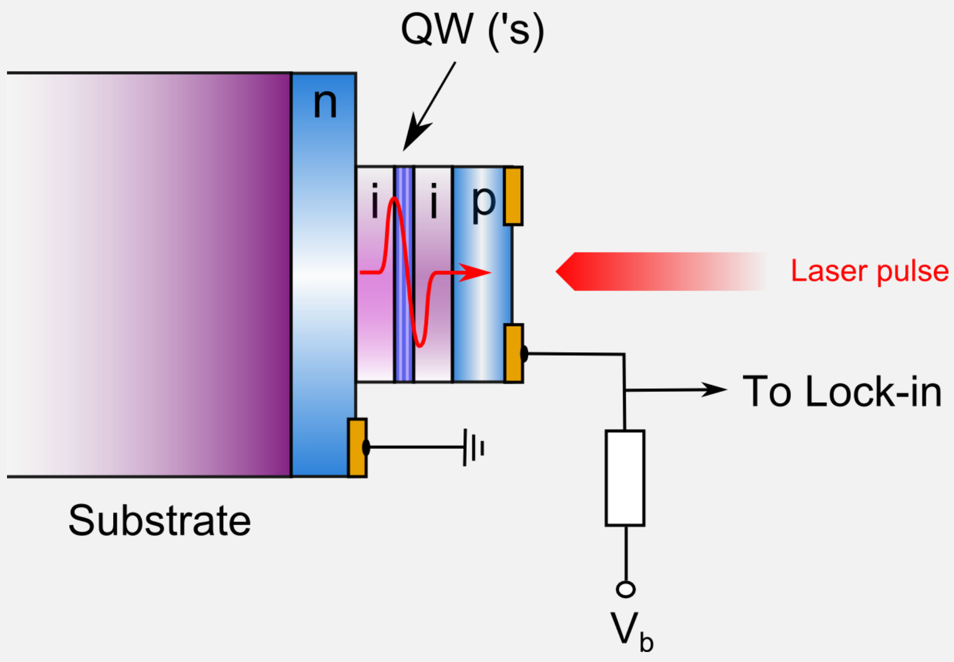


This additional periodicity leads to a folding of the acoustic phonon dispersion curve.

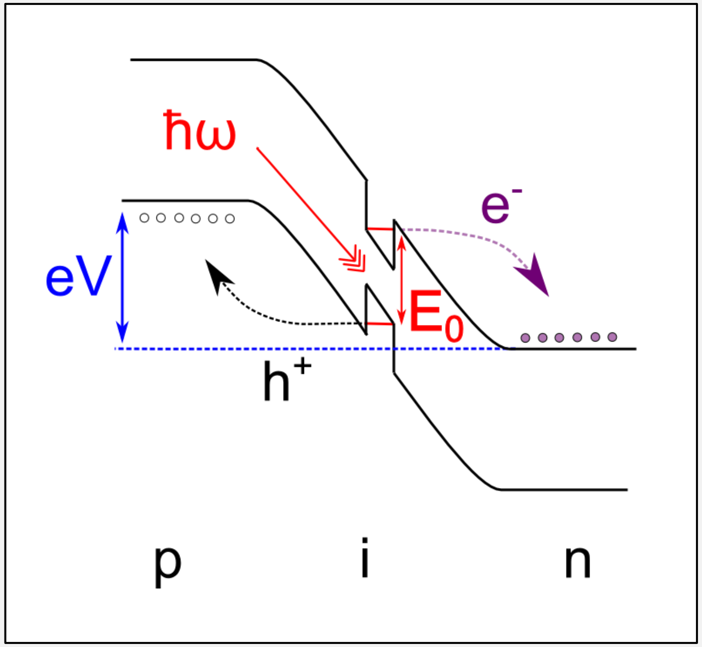
When a SL is excited by a pulsed laser high frequency phonons are emitted.

The p-i-n photodiode detector

The detection scheme used in this experiment is in the order of 100 X more sensitive than other coherent detection techniques.



Schematic of detection scheme



Band structure of p-i-n under reverse bias

The p-i-n photodiode detector

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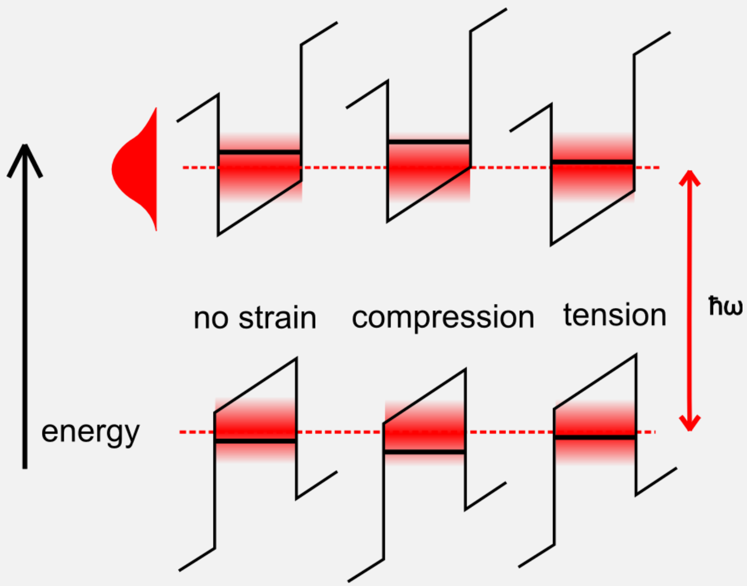
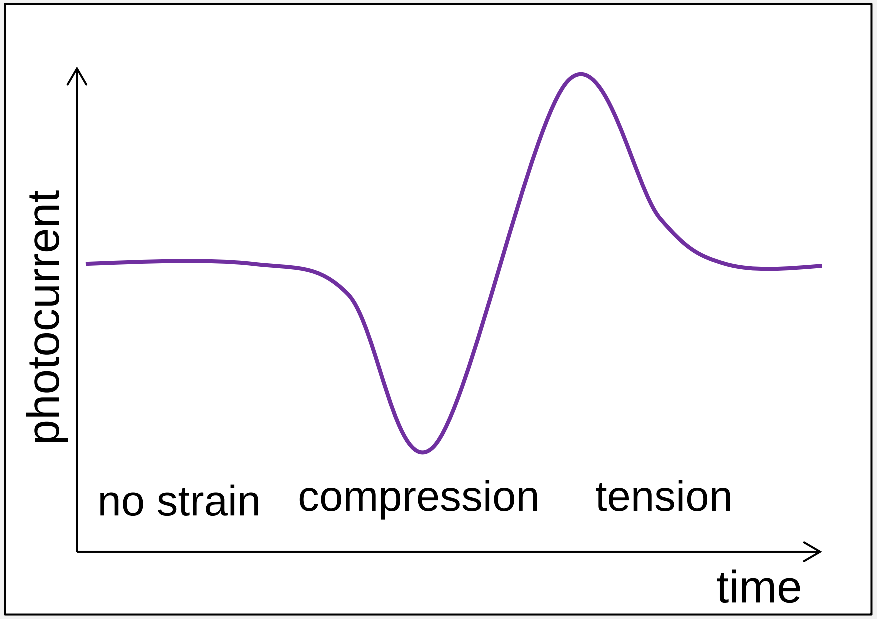
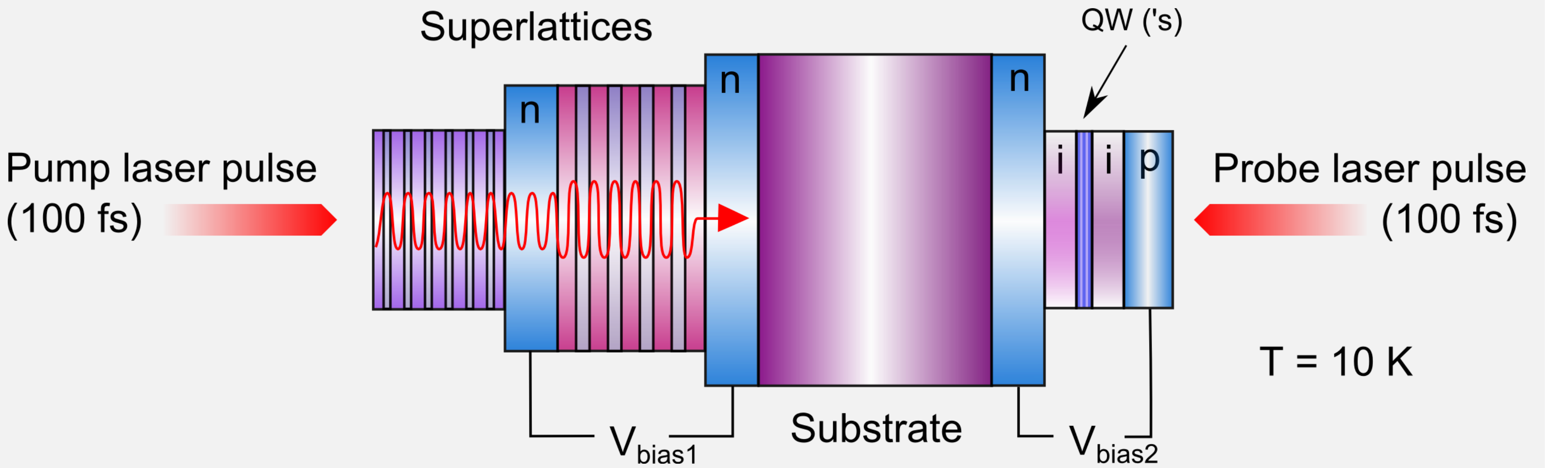
When an acoustic wave passes through the quantum well (QW) in the p-i-n, the strain shifts the QW energy level in and out of resonance with the laser energy causing a change in the photocurrent measured on the device.





[Moss et al., Phys. Rev. B. **83,** 245303, (2011)]

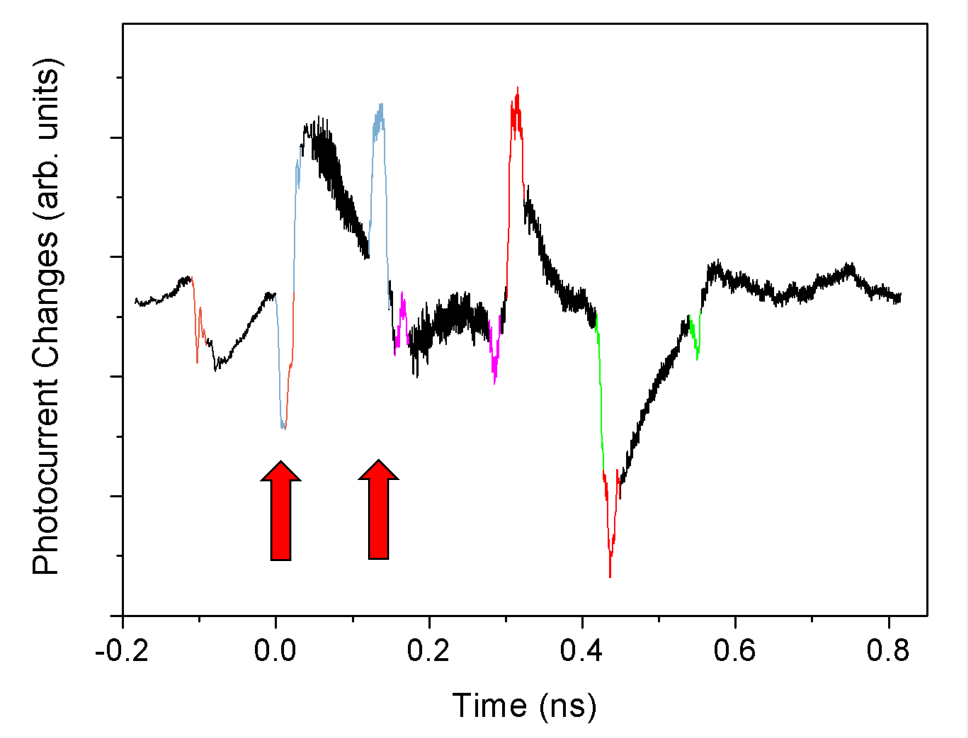
Experiment

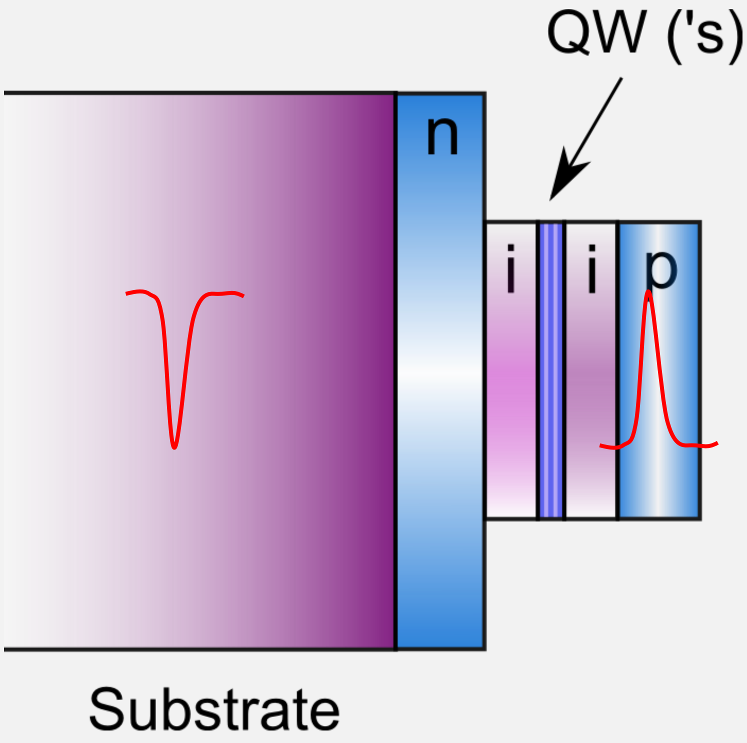


Both sides of the sample are processed to allow the application of an electrical bias.

A high frequency sound is generated in the top SL and the effect of passing it through the SASER SL is investigated.

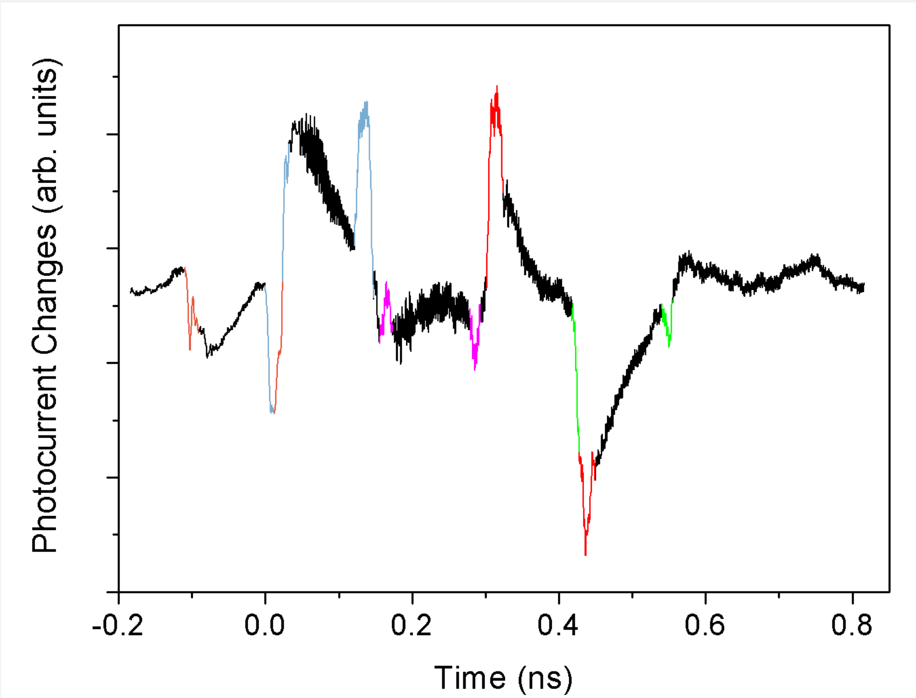
Origin of pairs of strain pulses

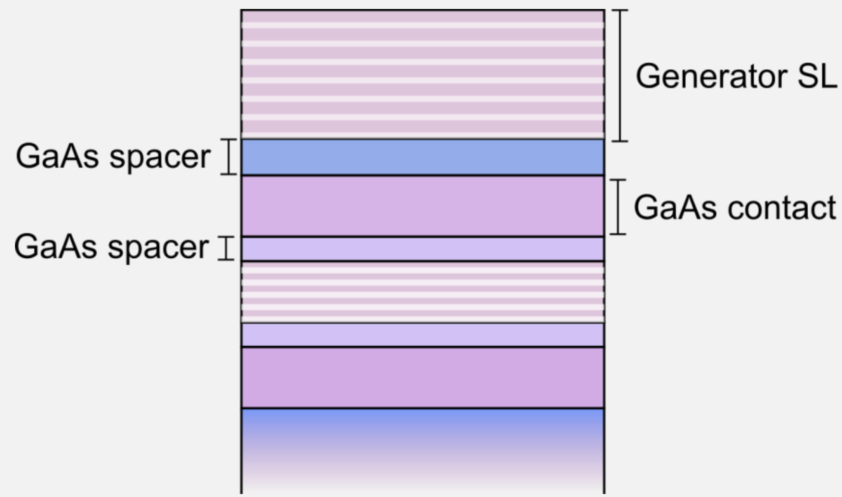




Each strain pulse appears twice in the trace due to being reflected in the p-i-n detector

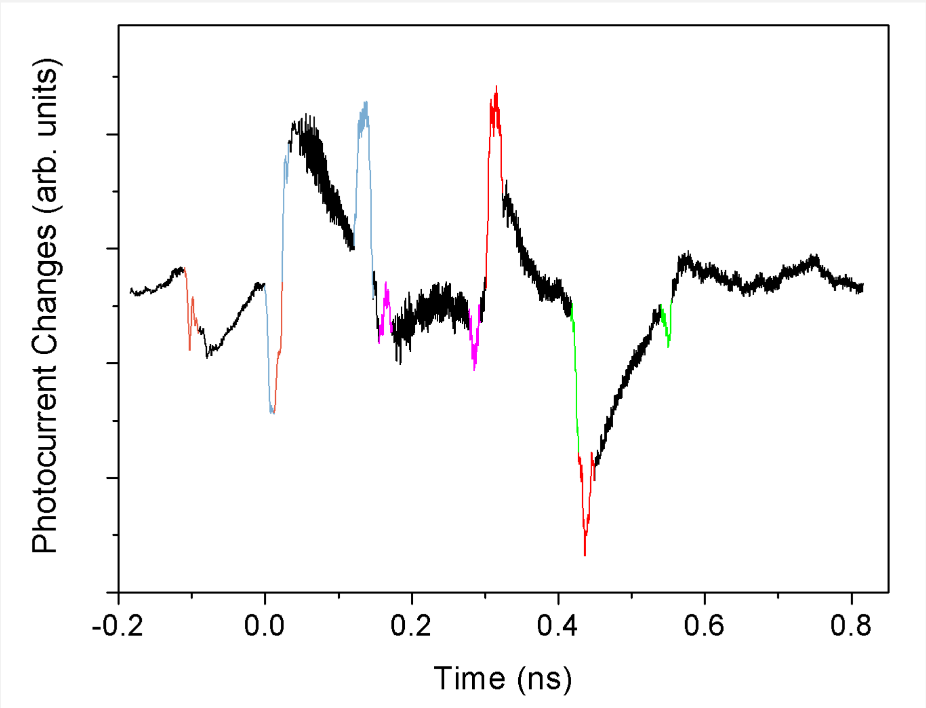
Origin of strain pulses

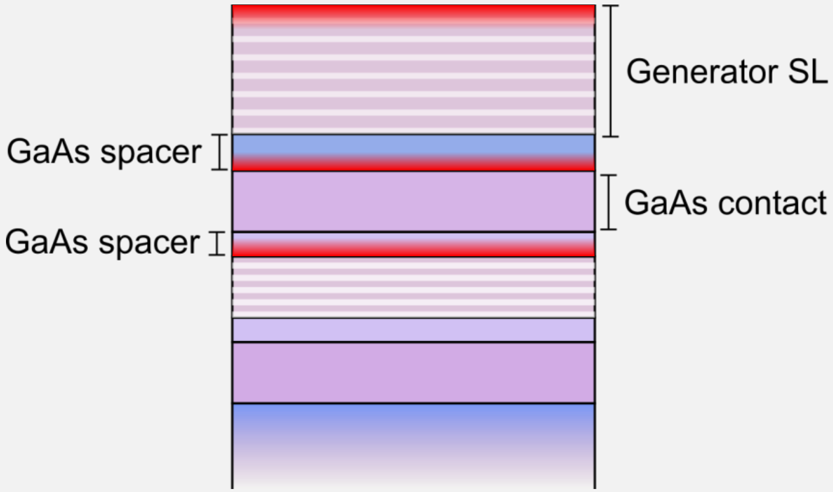




Strain pulses are generated in several layers in the SL structure and also reflected within it before travelling to the detector

Origin of strain pulses





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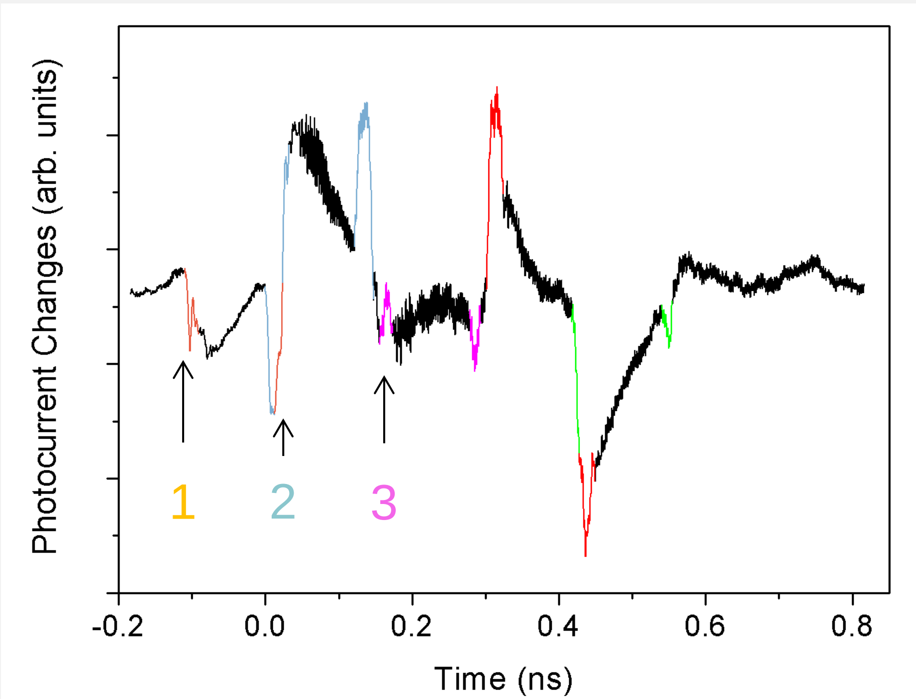
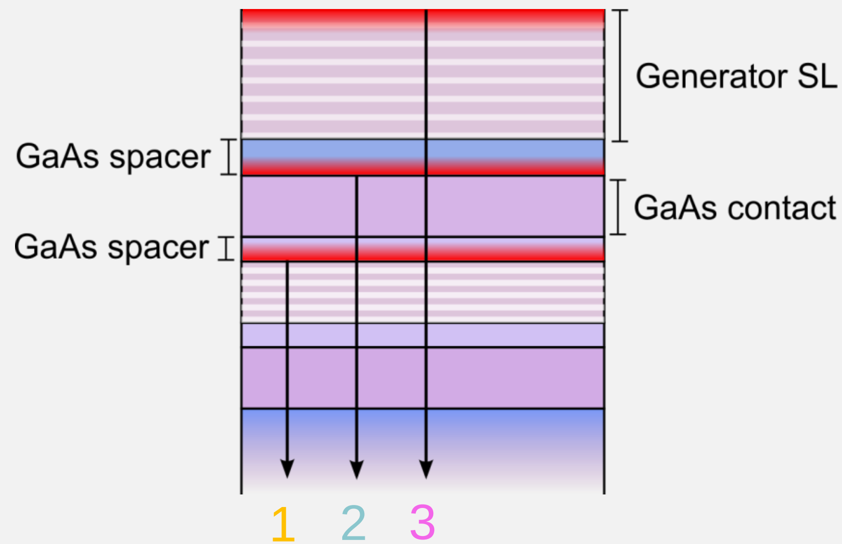
Origin of strain pulses





Strain pulses are generated in several layers in the SL structure and also reflected within it before travelling to the detector

Origin of strain pulses

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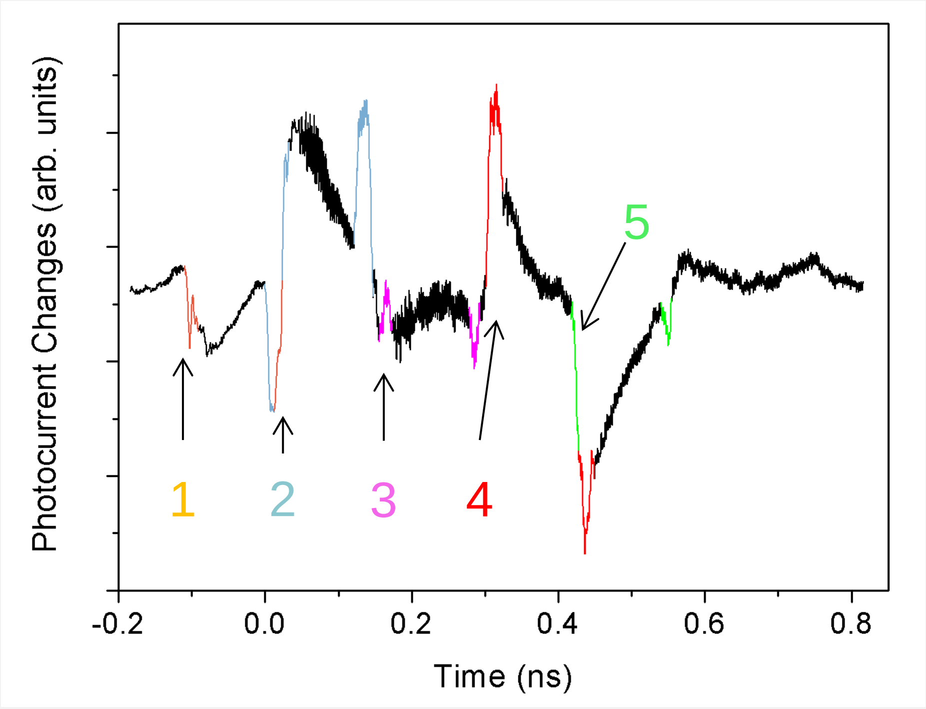
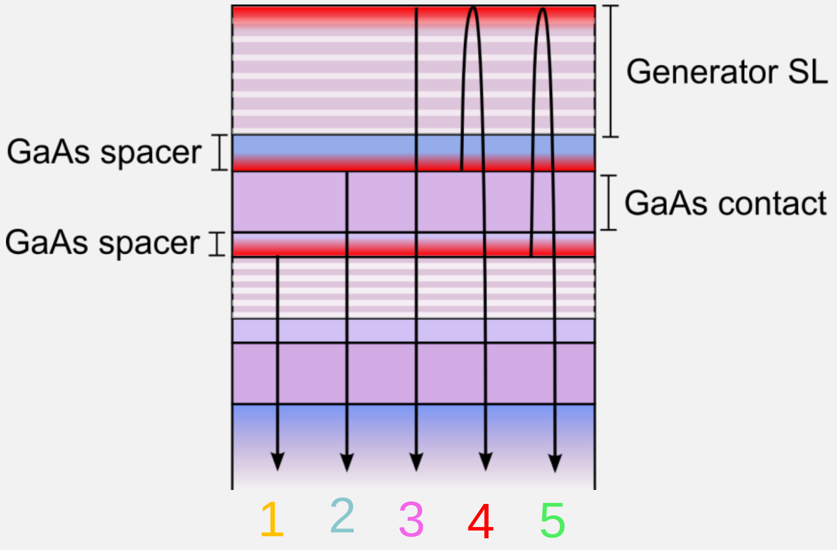
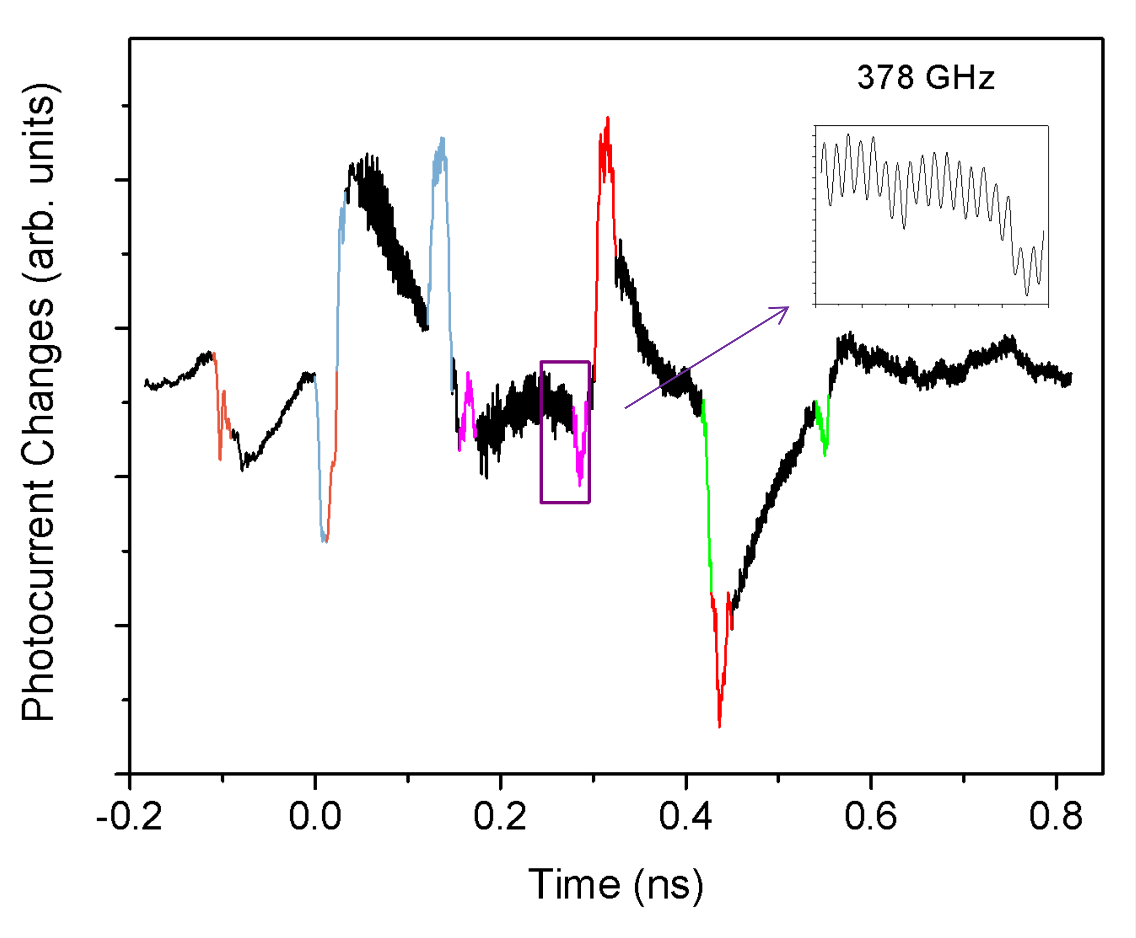




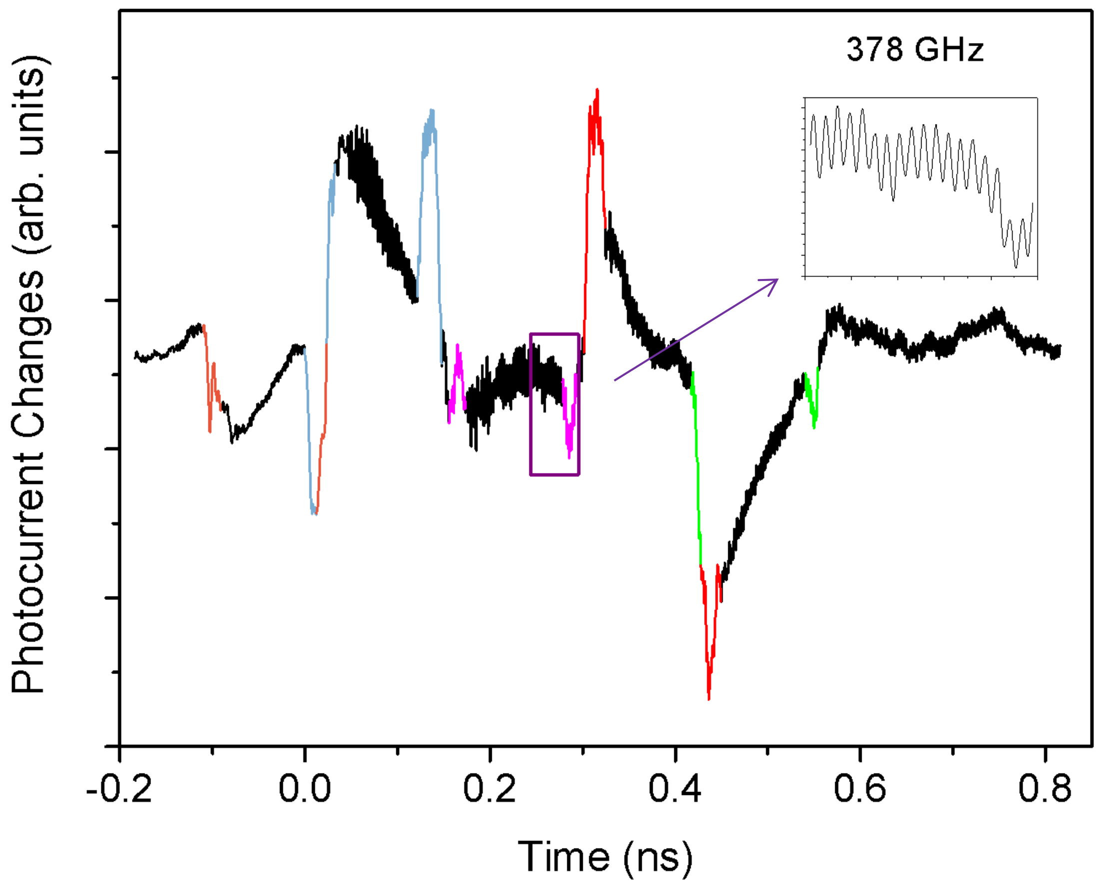
Strain pulses are generated in several layers in the SL structure and also reflected within it before travelling to the detector

Output of SL



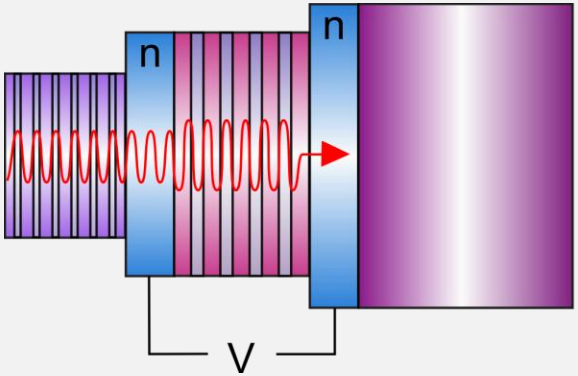
The 378 GHz zone centre mode emitted from the upper SL can clearly be seen throughout this trace.

Output of SL

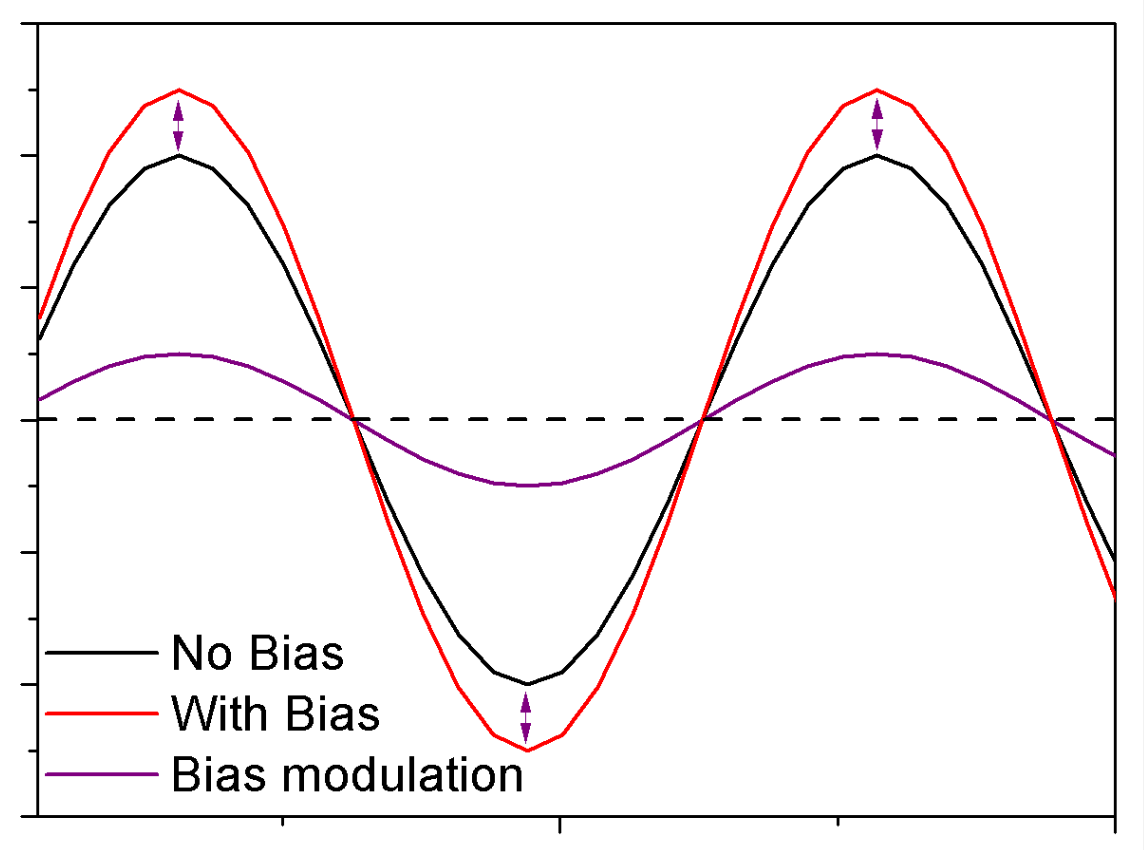


The 378 GHz zone centre mode emitted from the upper SL can clearly be seen throughout this trace.

We are interested in the effect bias has on this mode.



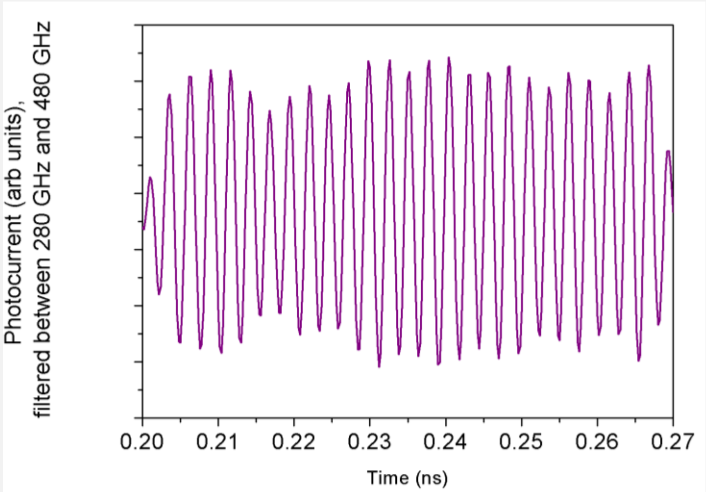
Bias modulation



Applying a bias to the gain SL causes small changes to the acoustic signal measured. These changes are isolated using a bias modulation technique.

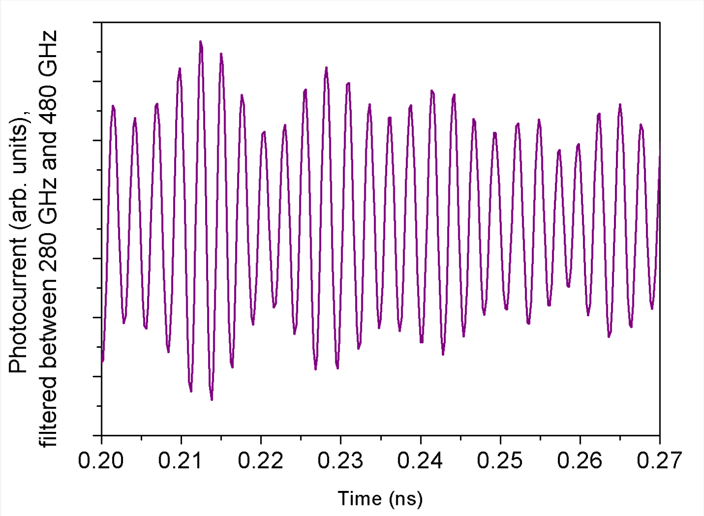
Signals with bias

Signal when no Bias is applied



When we apply a bias to the gain SL we see a high frequency is affected.

Changes in signal caused by bias



Signals with bias

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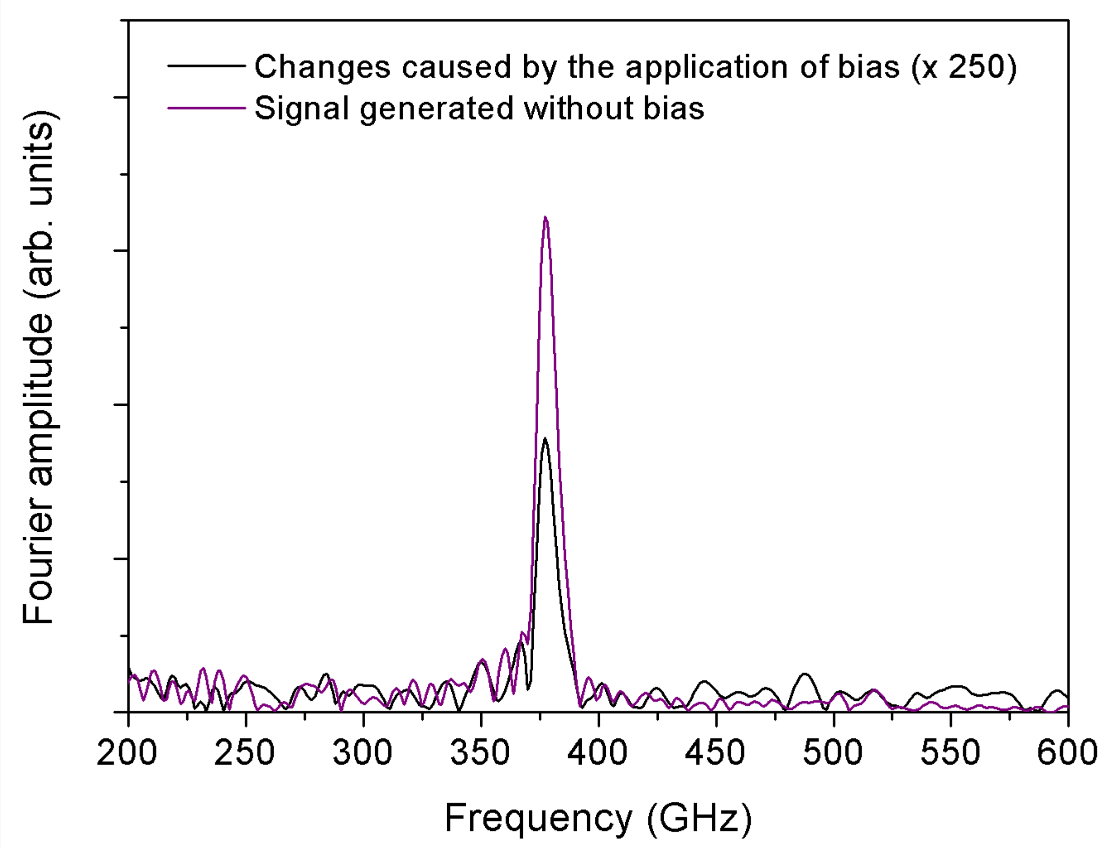
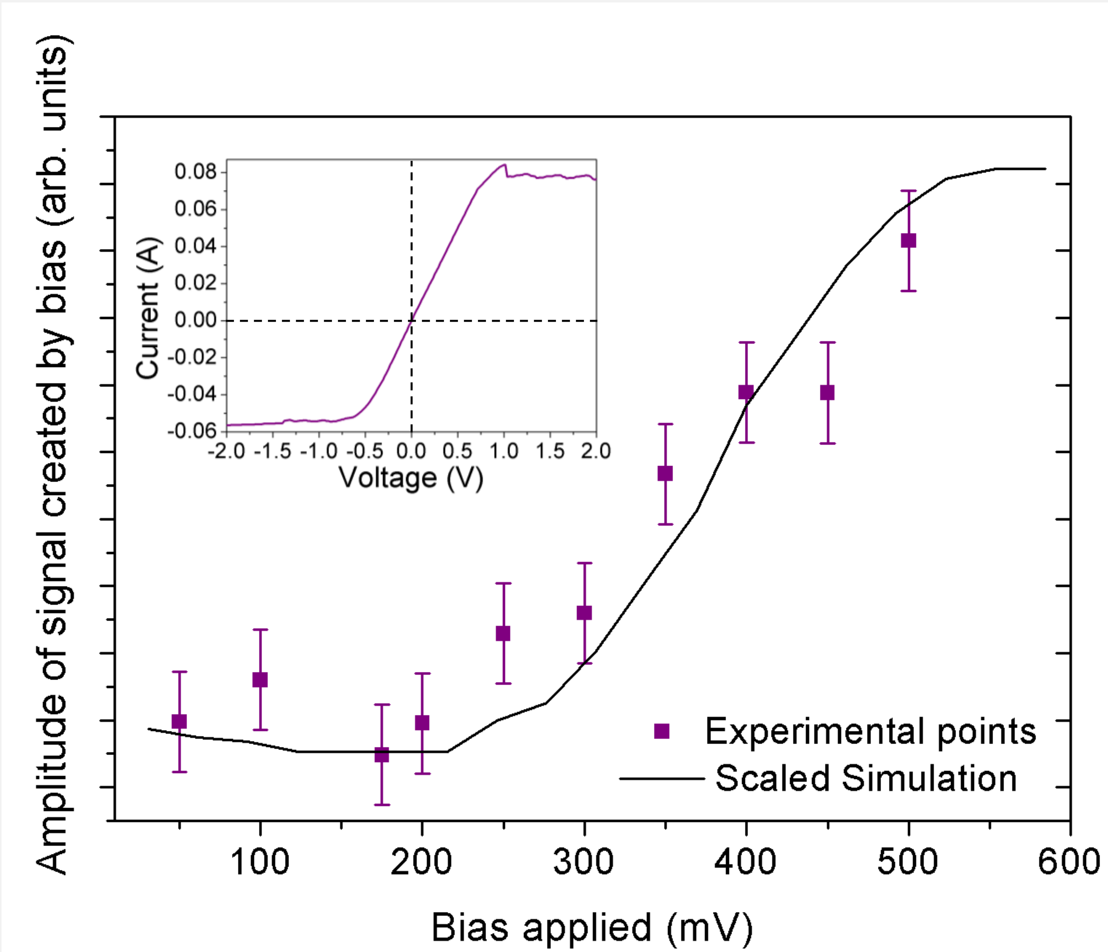


Taking a Fourier transform. We see the 378 GHz signal generated by the top SL appearing clearly in the both signals.

Bias dependence



The size of the effect caused by bias is increased as the magnitude of bias applied to the saser SL is increased.

The maximum level of gain seen in this device corresponds to a gain coefficient of ~200 cm^{-1}

[Beardsley et al., New J. Phys. **13,** 073007, (2011)]

Conclusions

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- This experiment demonstrates a THz acoustic “lab on a chip” technique. A coherent source and detector are used to investigate a potential acoustic device, the saser amplification SL.

- Monitoring the output of a single-pass amplification saser device suggests that coherent amplification is occurring in the device.

Acknowledgements

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