Synthetic optical holography for phase resolved Terahertz nano-imaging at sub-50 nm resolution

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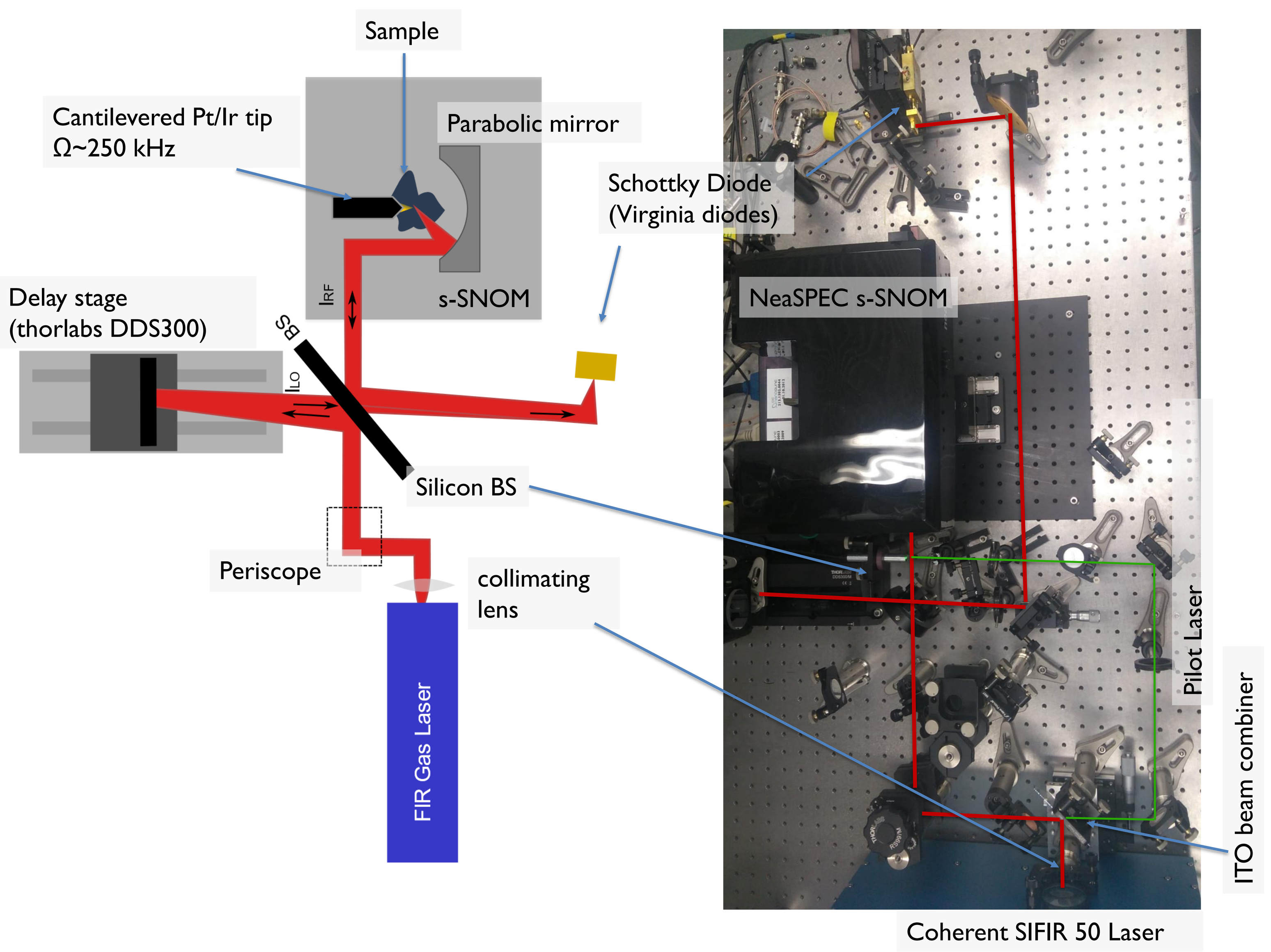
Abstract

We extend synthetic optical holography (SOH) [1] to the THz frequency range for fast, amplitude and phase resolved nano-imaging based on a scattering scanning near-field optical microscopy (s-SNOM). A THz gas laser is used for illumination and the scattered light is interferometrically detected by a Schottky diode operating at room temperature [2]. We demonstrate the systems capabilities on an ion implanted Silicon test structure [3]. Subsequently we image a Au/CsI boundary and find strong frequency dependent material contrast in accordance with a phonon-resonance at 2 THz [4,5].

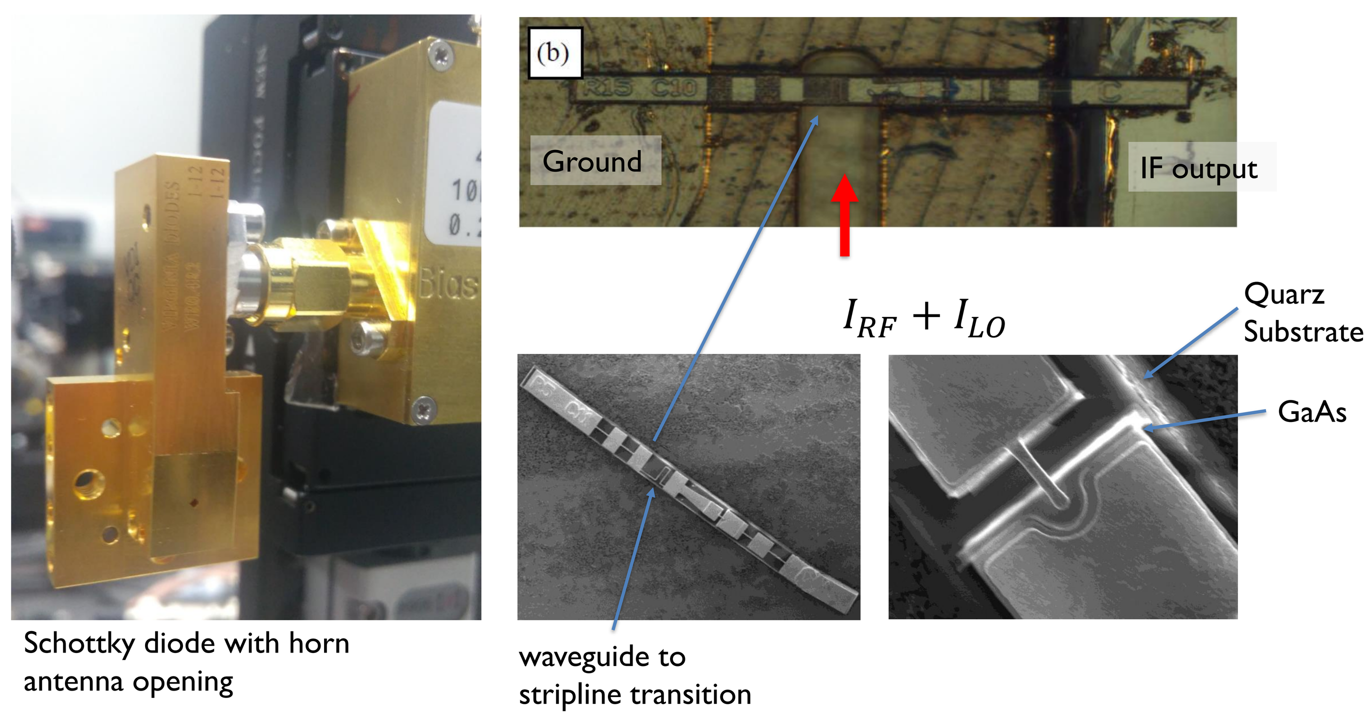
[1] M. Schnell et al., *Nature Communications*, **5**, 3499, 2014
[2] T. Schweinböck and S. Hommel, *Microelectronics Reliability*, **54**, 2070-2074, 2014
[3] J. Hesler et al. *IRMMW-THz 36th International Conference*, IEEE 2011
[4] E. Plyler, N. Acquista, *JOSA*, **48**(9), 668-669, 1958.
[5] R. Hillenbrand et al., *Nature*. **418** 2002.

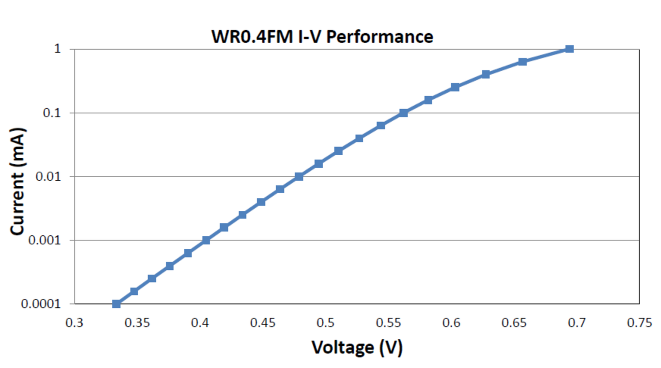
Experimental Setup

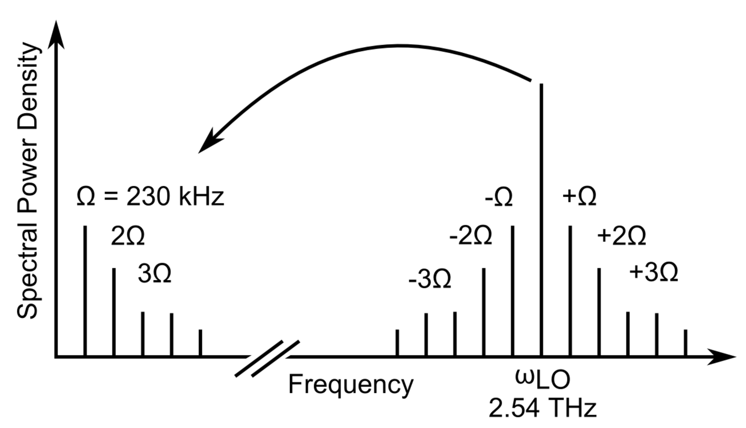


- SIFIR 50 THz gas laser, discrete lines from 1-6 THz
- collimated beam waist after lens ~ 5 mm
- Imaging using commercial Pt/Ir coated AFM tips (10 μm long) with NeaSNOM microscope
- Phase of reference beam controlled by 300 mm long linear stage
- Schottky diode detector with 0.8 THz 3 dB bandwidth at center frequency of 2.5 THz, large mixing gain due to strong local oscillator (i.e. reference arm)

Schottky Diode Detector

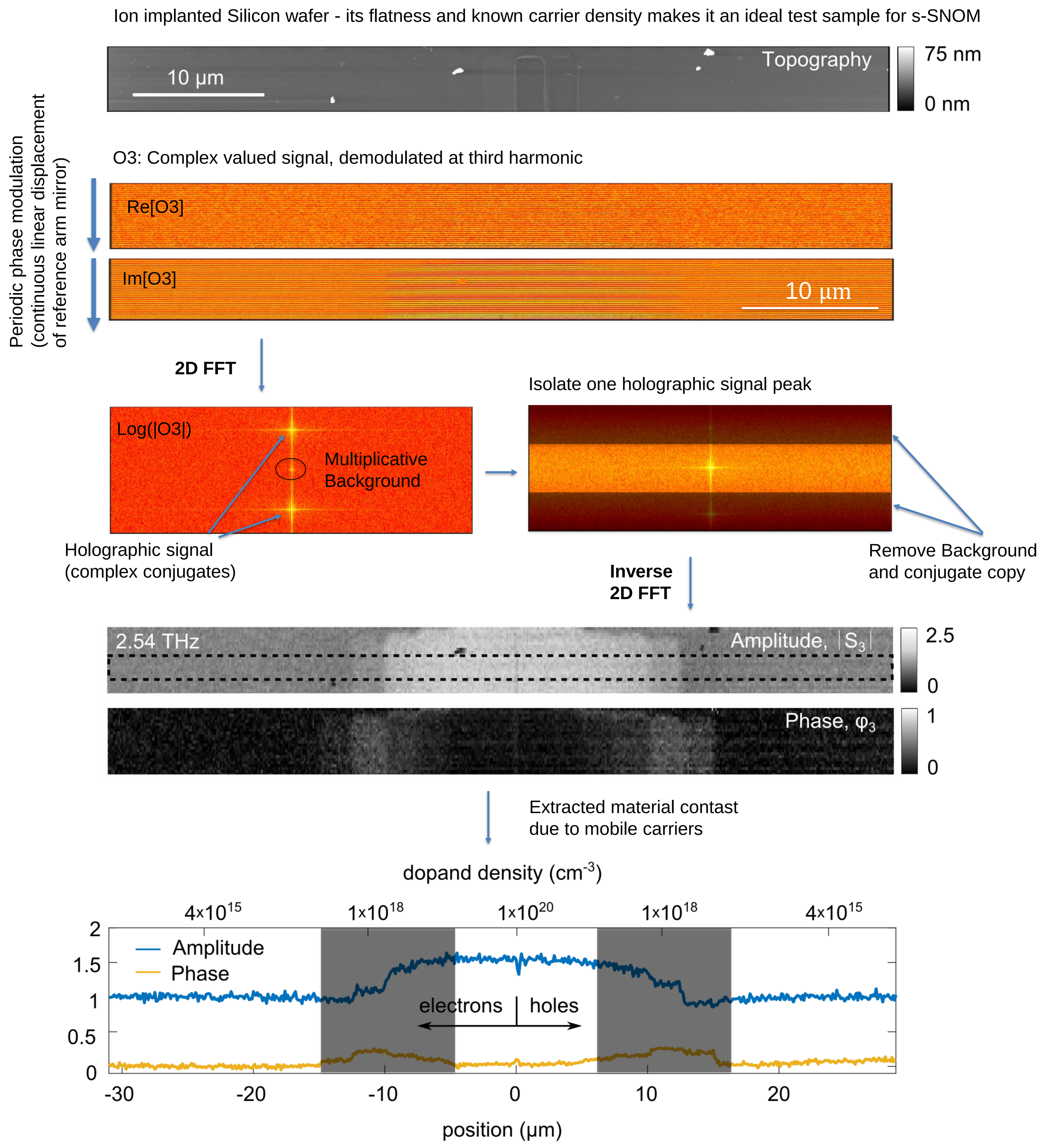






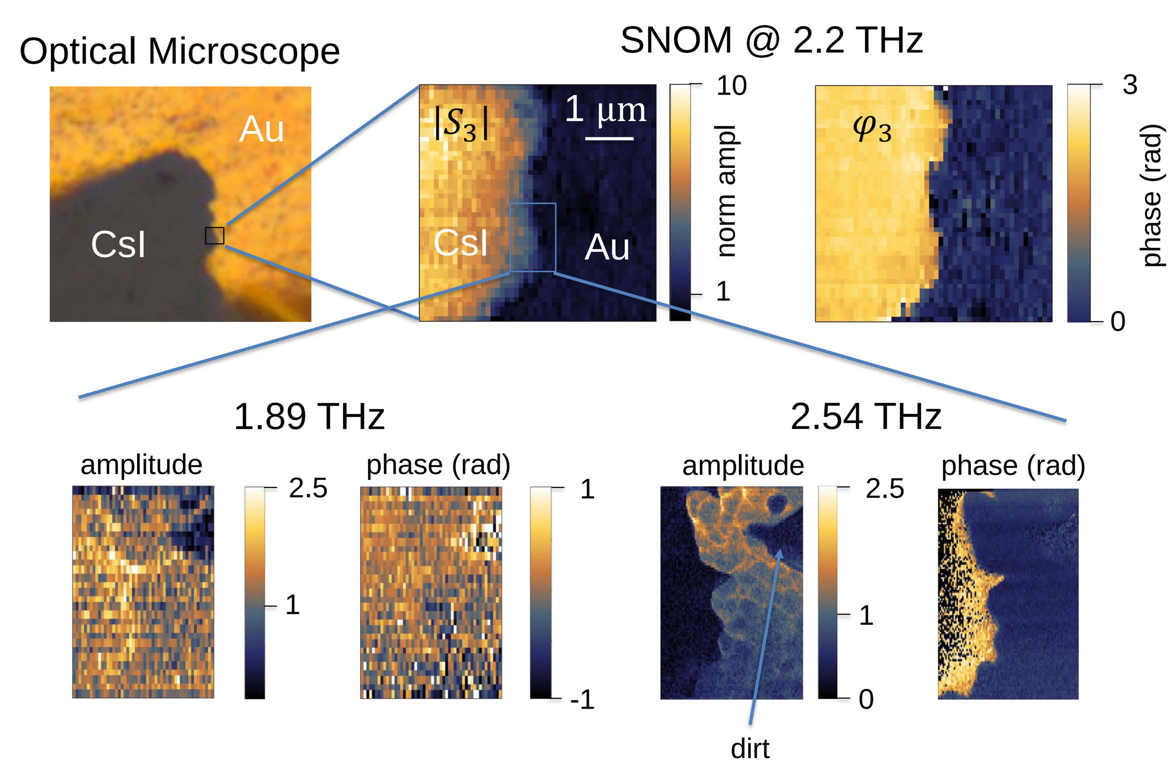
- Electric field mixing due to non-linear IV-curve
- Drive diode close to saturation current to enhance square law response
- Linear regime given by $E_{LO} \gg E_{scat}$ (typical LO-power is 1 mW), ideal to detect small, tip-scattered signals on top of large far-field background

Synthetic optical holography

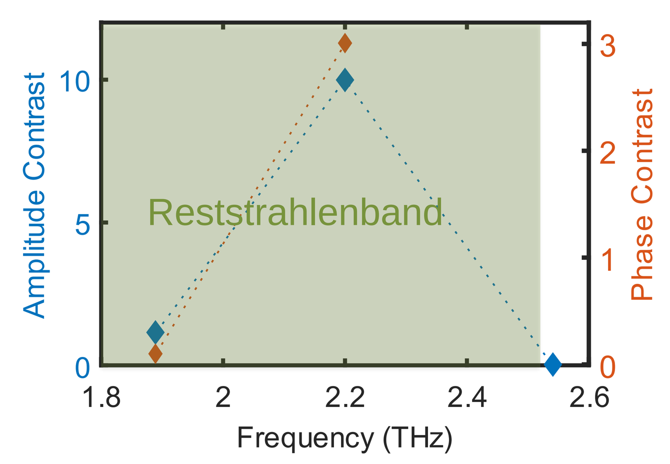


- Multiplicative background (which persits in the scattered ligth even for high demodulation harmonics) can be removed by SOH
- We find good agreement of measured s-SNOM phase and amplitude contrast with nominal carrier densities
- s-SNOM at 2.5 THz is sensitive carrier probe at densities from $10^{17} - 10^{19}\mathrm{cm}^{-3}$

Phonon Resonance in CsI Crystal



- Strong, frequency dependent material contrast
- At 2.54 THz signal on CsI below noise level
- At 2.2 THz, CsI is 10x more reflective in the near-field in respect to Au
- At 1.89 THz similar response from CsI and Au
- Measurements are consistent with a phonon in CsI at 2 THz



Conclusion

- All room-temperature tabletop THz-nearfield imaging
- Fast image acquisition thanks to large gain from mixing with local oscillator
- SOH allows to remove multiplicative background which does not vanish by simply demodulating at high harmonics of the tip
- Setup benchmarked with ion implanted dopands in Silicon and phonon resonance in CsI

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