

Quantum Up-Conversion of Squeezed Light from 1550 nm to 532 nm

Jan Griesmer,^{1,2} Christoph Baune,^{1,3} Axel Schönbeck,^{1,3}
Christina Vollmer,¹ Jaromír Fiurášek,⁴ and Roman Schnabel^{1,3,*}

¹*Institute for Gravitational Physics, Leibniz University Hannover and Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institute), Callinstrasse 38, 30167 Hannover, Germany*

²*Institute for Solid State Physics, Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany*

³*Institute for Laser Physics and Center for Optical Quantum Technologies, University Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany*

⁴*Department of Optics, Palacký University, 17. listopadu 12, 77146 Olomouc, Czech Republic*

Quantum metrology utilizes non-classical states to improve the precision of measurement devices. In this context, strongly squeezed vacuum states of light have proven to be a useful resource. They are typically produced by spontaneous parametric down-conversion, but have not been generated at shorter wavelengths so far, as suitable non-linear materials do not exist. Frequency up-conversion of light provides access to hitherto inaccessible wavelengths.

Vollmer et al. demonstrated squeezed vacuum states at 532 nm with a noise suppression of 1.5 dB [1]. These were generated by up-conversion of squeezed states at the telecom wavelength 1550 nm. We report on improvements of the same optical setup to achieve stronger squeezing. In particular this involves characterization of the initial squeezing at 1550 nm, better up-conversion efficiency and an advanced homodyne detection setup at 532 nm. We show the application of squeezed states to improve the sensitivity of a Mach-Zehnder interferometer.

Our setup is shown in Fig. 1. We use a strong field at 532 nm to pump a non-degenerate optical parametric oscillator (NOPO), which produces bright fields at 1550 nm and 810 nm. They are separated from each other with a dichroic beam splitter (DBS). The field at 1550 nm acts as the pump for the second harmonic generator (SHG) producing a beam at 775 nm. This is used to pump the optical parametric amplifier (OPA), generating a squeezed vacuum field at 1550 nm via parametric down-conversion. A squeezing value of -8.4 dB was measured. Both the squeezed 1550 nm field and the pump at 810 nm are coupled

into the sum-frequency generation cavity (SFG). Here, the squeezed noise statistics are transferred to 532 nm. A small fraction of the initial 532 nm NOPO pump beam is tapped off with a beamsplitter (BS) and serves as a local oscillator for balanced homodyne detection. The setup ensures that the squeezed field has exactly the same frequency as the local oscillator.

We demonstrated frequency up-conversion of strongly squeezed vacuum states of light with a conversion efficiency of up to 90.2%. The squeezing resonator being resonant for the pump light (doubly resonant) helped to produce good squeezing levels, even for the low pump power available. Furthermore, the detection efficiency of the homodyne detector was optimized by re-focussing reflected light onto the chip. We achieved a noise reduction of 5.5 dB below vacuum with the converted squeezed vacuum. It corresponds to 18 dB of anti-squeezing. This implies 27% overall losses, which matches our theoretical expectations. The spectrum shows more than 3 dB of squeezing below 20 MHz and is in excellent agreement with our theoretical model.

The squeezed 532 nm field was injected into one input port of a Mach-Zehnder interferometer. This was locked to mid-fringe and a phase modulation was applied in one arm via electro-optic modulation. The signal-to-noise ratio was significantly improved through the application of squeezing.

This result verified that highly efficient up-conversion of squeezed vacuum states opens the possibility of sensitivity enhancements of phase measurements, such as those for gravitational wave detectors, where the operating wavelength is reduced to 532 nm [2]. Furthermore, spectroscopic measurements might greatly benefit from this technique, as in principle the entire visible wavelength regime can be covered by means of quantum up-conversion.

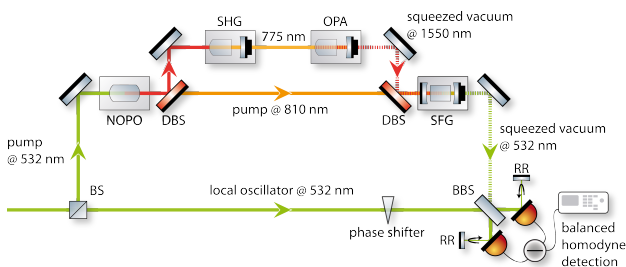


Fig. 1. Experimental setup to generate vacuum squeezed states of light at 532 nm via up-conversion from 1550 nm

* roman.schnabel@aei.mpg.de

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