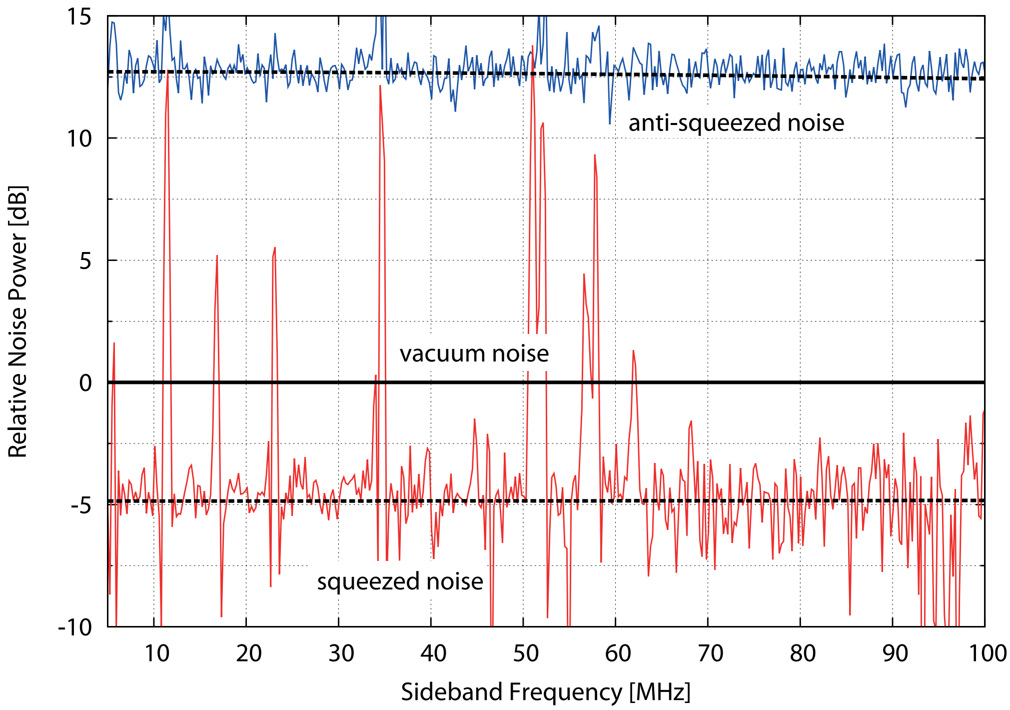

Fig. 3. MHz bandwidth measurement. Squeezed-vacuum measurement from 5 to 100 MHz sideband frequency using a homodyne detector with 99 % quantum efficiency. We measured squeezing (red) of 4.8 dB and anti-squeezing (blue) of 12.7 dB with respect to the vacuum noise level (black). The measurement is dark-noise corrected. The measured squeezing below 20 MHz is, however, not influenced by the dark noise correction due to the detector's low dark noise at low frequencies. The total detection efficiency was fitted to be 72.5 %. The dashed black lines correspond to our numerical simulation. The peaks in the squeezing spectrum originated from electronic pick-up of the homodyne detector due to antenna effects and are also visible in the detector's dark noise.

homodyne detector's photo diodes nor the operational amplifiers. Due to the high electronic gain and the high local oscillator power, the detector yielded a dark-noise clearance of 20 dB at 5 MHz decreasing to less than 3 dB at 100 MHz. The high transimpedance gain as well as the finite speed of the photo diodes were responsible for the decreasing dark-noise clearance and limited the detector's bandwidth. At frequencies above 100 MHz the low dark-noise clearance prevented useful squeezing measurements.

Our squeezed-vacuum measurement used a 5 mW local oscillator power, 375 mW harmonic pump power for the squeezing resonator, a RBW of 500 kHz, a VBW of 3 kHz and a sweep time of 170 ms. The measurements without dark-noise correction yielded a non-classical noise suppression of about 4.8 dB at 5 MHz and about 2 dB at 100 MHz, which was limited by a dark-noise clearance as low as 3 dB. Figure 3 shows dark noise corrected measurements of squeezed and anti-squeezed quadratures, normalized to the vacuum noise level. We measured squeezing values of up to 4.8 dB and anti-squeezing of up to 12.7 dB. The sharp peaks in the spectrum originated from electronic pick up from the power supply due to antenna effects and a Pound-Drever-Hall (PDH) modulation frequency at 24 MHz.

Using the squeezed light measurement we deduced the photo diode detection efficiencies to be around 99 % with a homodyne efficiency of $\eta = \beta^2 \cdot (1 - \mathrm{L}) = 0.73$. This refers to a total

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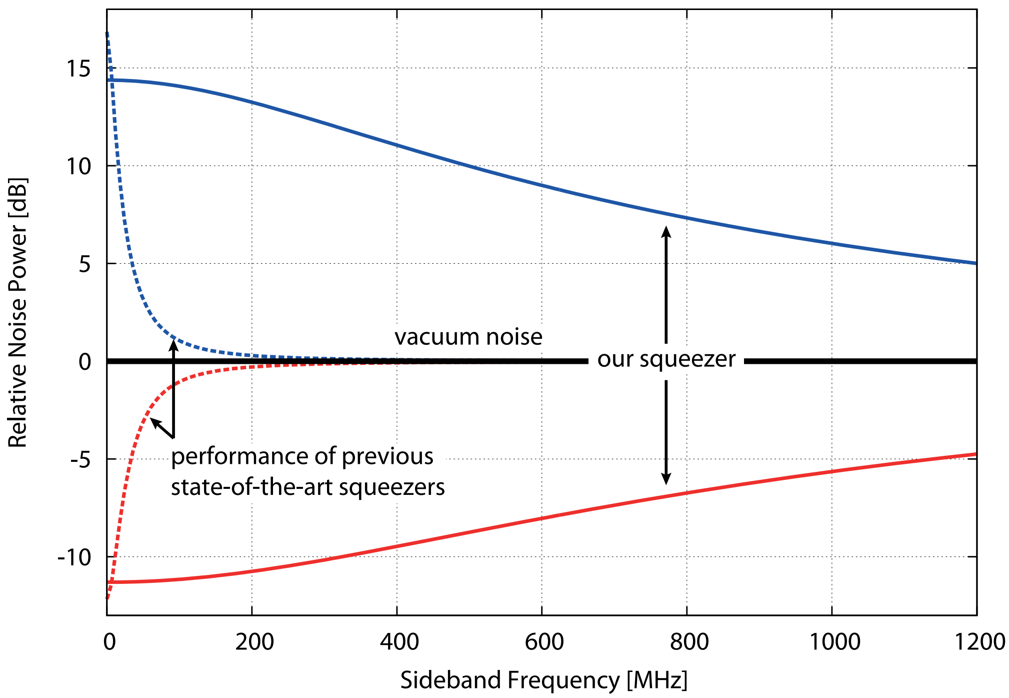

Fig. 4. Numerical simulation using N.L.C.S. for a typical squeezing resonator as in [13] (dashed lines) and the monolithic GHz bandwidth squeezing resonator reported in this experiment (solid lines). Our simulation assumes a total detection efficiency of 96 %, as realized in [13] for low bandwidths. The squeezing source reported here generates almost the same squeezing strengths as state of the art sources. Its bandwidth does, however, offer significantly increased data rates in entanglement-based continuous-variable quantum key distribution.

detection efficiency of 0.725. The measured squeezing value between 5 and 100 MHz is thus limited mainly by the homodyne visibility β and the optical path losses L.

We again simulated the measured spectrum with the given parameters for the cavity (including linewidth), the pump field and the different homodyne detection efficiency (see section 3) using N.L.C.S. The dashed lines in Fig. 3 show the simulation for squeezing and anti-squeezing, respectively.

5. Conclusion

Our work introduces a new, only 2.6 mm long, monolithic crystal cavity. We demonstrated the generation of a broadband squeezed state at 1550 nm ranging from 5 MHz to 1.2 GHz sideband frequency. Two different homodyne detectors were used to perform consecutive measurements for different frequency bands. We used the same optical parametric pump power of about 375 mW for both measurements. A commercially available balanced photo receiver directly observed squeezing of up to 2 dB between 10 MHz and 1.2 GHz. A second measurement used a home-made homodyne detector based on photo diodes with quantum efficiencies near unity. The latter directly observed a non-classical quantum noise suppression of up to 4.8 dB from 5 to 100 MHz.

The two measured homodyne detector spectra where numerically simulated using identical parameters, but with different quantum efficiencies for the detectors. The simulations are self-

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consistent and in very good agreement with the measurements.

Based on our analysis, the measured squeezing was limited by the homodyne detector visibility (90 %), propagation loss (10 %) and partly by the quantum efficiencies of the photo diodes. Our analysis suggests that the current squeezing resonator design should enable the observation of squeezing up to about 10 dB with a bandwidth in the GHz regime. Such a measurement would require a high-speed homodyne detector with GHz bandwidth, with 99 % detection efficiency and an increased homodyne visibility. We simulated our squeezing resonator setup with a total detection efficiency of 96 % as achieved in [13] for low bandwidths. The simulation shows around 10 dB of non-classical noise suppression at MHz frequencies and more than 5 dB at GHz frequencies (Fig. 4).

Our squeezed-light resonator is a possible source for high-speed quantum key distribution. The source can be used to create two-mode squeezed states and therefore entanglement in the GHz band [20–22]. Our current design is capable of producing similarly high squeezing values as state of the art narrow-band squeezing resonators. The high squeezing bandwidth does, however, offer significantly improved QKD data rates. The squeezing strength is already limited by losses in fiber-based networks. Therefore, our scheme proposes a possible solution for high-speed quantum key distribution via squeezed states of light using optical fibers.

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