Hypersonic frequency combs in silicon membranes

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A hypersonic acoustic frequency comb is generated in a thin silicon membrane by exciting acoustic pulses in a thin aluminum film which is deposited on top of the membrane. Due to the air-interfaces at the surfaces of the Al/Si-system a cavity is formed. The spacing of the individual modes is determined by the cavity length. With this technique it is possible to excite acoustic frequencies up to 500 GHz and combs with up to 45 modes. The combs can both be used to evaluate intrinsic material properties of Al and Si as well as to measure extrinsic properties, like adhesion strength between the two layers. A frequency shift of the higher harmonics due to the different mechanical properties of the two layers is observed with great precision. By comparing the individual reflected pulses it is possible to obtain the lifetimes for an Al/Si layer system over a wide frequency range.

We use a specific optical pump-probe spectroscopy to generate and detect the coherent acoustic phonons which is called asynchronous optical sampling (ASOPS) [1]. For ASOPS two coupled femtosecond Ti:sapphire oscillators with a repetition rate of 800 MHz are used. By actively stabilizing the repetition rates to a fixed offset, the time delay between the two laser pulses is monotonically changed. This allows measuring a time window of 1.25 ns in 0.2 ms. The membranes measured are fabricated from a commercially available Si-on-insulator wafer, which are wet-etched from the backside with potassium hydroxide using a silicon-nitride etch mask, resulting in ~340 nm thick Si membranes. To generate different frequency combs (e.g. different spectral pulse shapes), systems with varying Al thickness (10-40 nm) were prepared.

By modeling the Al/Si-interface using a spring between the two layers, we are able to derive an analytical term for the spectrum of the generated stress, which only depends on the material parameters and a variable spring constant. For different adhesion strength both in the experiment and the model an additional dip in the spectrum appears, corresponding to the acoustic eigenfrequency of the Al film. The eigenmode oscillation affects strongly both the damping and the phase of this frequency regime in the spectrum.

This work was supported by the DFG (SFB 767).

References:

[1] A. Bartels, R. Cerna, C. Kistner, A. Thoma, F. Hudert, C. Janke, T. Dekorsy, Rev. Sci. Instrum., 78, 035107, (2007).
[2] M. Grossmann, M. Klingele, P. Scheel, O. Ristow, M. Hettich, C. He, R. Waitz, M. Schubert, A. Bruchhausen, V. Gusev, E. Scheer, T. Dekorsy, Phys. Rev. B, 88, 205202, (2013).