Measurement of the acoustic loss at GHz frequencies using laser-excited plate resonances

Ryzy M[(1)*], Grünsteidl C[(1)], Istvan V[(2)], Thomas B[(2)]

(1) Research Center for Non-Destructive Testing GmbH, Linz, Austria (2) Qorvo, Inc., Apopka, FL 32703 USA

*Corresponding author's email: martin.ryzy@recendt.at

Background – State of the art wireless telecommunication is based on the transmission of electromagnetic (EM) waves at GHz-frequencies. For filtering broadband EM signals in telecommunication devices, electro-acoustic resonators (like BAWs or SAWs) are used. Filter manufacturers desire a precise knowledge of the acoustic loss (attenuation) of their constituent materials at the operating frequencies. This benefits device optimization and the design of filters for new generation telecommunication standards (like 6G).

Laser ultrasonic (LUS) techniques have a small spatial footprint and thus provide a unique way for exciting and detecting acoustic waves at high frequencies. Particularly, plate-resonance can be effectively accessed with LUS and they are well suited for elastic material characterization [1]. As their resonance frequency inversely scales with the plate thickness, samples can be tailored to target specific acoustic frequencies. In recent years, the boundaries of associated LUS techniques were continuously extended, so that nowadays measurements at GHz frequency can be readily performed [2]–[4].

Methods – A frequency-domain laser ultrasound setup is used for the measurement of plate-resonances in free-standing metallic plates (Fig. 1 (a)). To obtain a series of resonance frequencies in the low GHz frequency regime, we produce micron-scaled samples by lithographic means. The decay-rate of two different resonance types, thickness stretch resonances and zero-group-velocity (ZGV) resonances, is obtained from recorded acoustic spectra (Fig. 1 (b) and (c)). For thickness stretch resonances, this directly yields the longitudinal acoustic loss. For ZGV resonances, two resonances at the same frequency are required to disentangle longitudinal and transverse wave attenuation. Therefore, two separate plates with different thicknesses are used, that provide that the first ZGV resonance in sample one and the second ZGV resonance in sample two appear at the same frequency. A mathematical model has been developed, that connects the ZGV decay rate with the fundamental attenuation coefficients α_L and α_T, for longitudinal and transvers waves.

Results – The longitudinal quality factor $Q = f/2\alpha_L$ of aluminium is obtained in a frequency range between 1.5GHz and 3GHz from a series of measurements (see for example Fig. 1 (b)) in six aluminium plates with thicknesses ranging from 1.1 to 2.15µm. The quality factor follows a frequency power-law with an exponent around -1.5 (see Fig. 1 (d)). Comparison with the theoretical thermoelastic damping limit suggests the presence of additional loss mechanisms like (grain-boundary) scattering or different intrinsic losses [4]. Measurements of the decay rate of the first ZGV resonance in a 1.1µm thick tungsten plate, and of the second ZGV resonance in a 1.8µm thick tungsten plate (Fig. 1 (c)) yield ZGV decay rates of $12.97\ 10^6 s^{-1}$ and $19.86\ 10^6 s^{-1}$ at a frequency of around 2.16GHz. Applying a derived linear model, longitudinal and transvers attenuation coefficients of $\alpha_L = 18.2\text{dBmm}^{-1}$ and $\alpha_T = 29.2\text{dBmm}^{-1}$ are obtained.

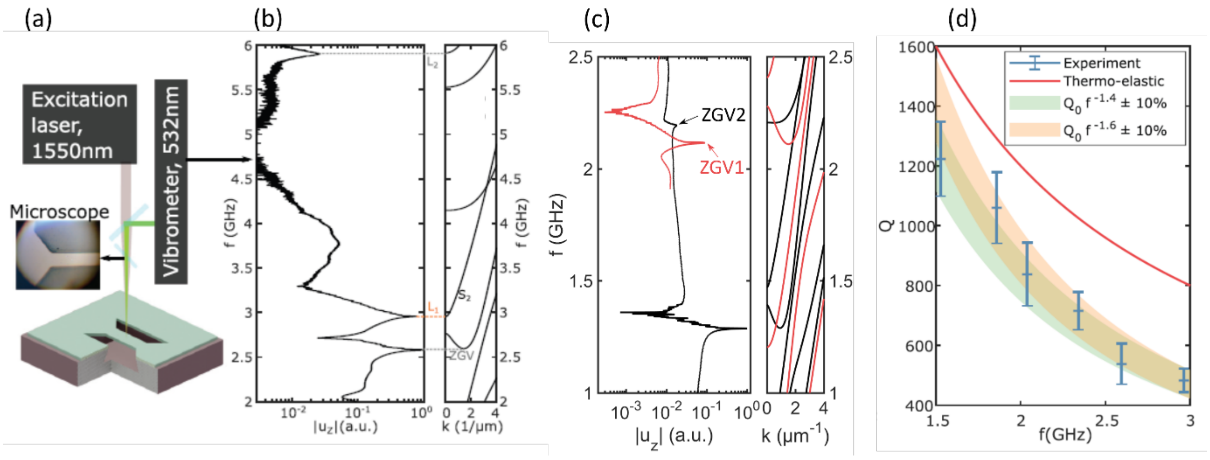

Fig 1 (a) Schematic of the used frequency domain laser ultrasound setup. (b) Measured acoustic spectrum and calculated dispersion curves of a 1.8µm thick aluminium plate. (c) Measured acoustic spectra and calculated dispersion curves of a 1.8µm (black) and a 1.1µm (red) thick tungsten plate. (d) Frequency dependence of the longitudinal quality factor of aluminium, obtained from a series of six aluminium plates with different thicknesses. The theoretical thermoelastic limit is shown as red solid line. Figures (a), (b) and (d) are extracted from reference [4].

Conclusions – Methods for the determination of the acoustic loss, based on the measurement of different types of acoustic plate resonances by laser-ultrasonic means are presented. Longitudinal loss at a certain frequency can be directly obtained from a single thickness stretch resonance. The simultaneous determination of longitudinal and transverse losses can be achieved by the measurement of two independent resonances at the same frequency, and the application of a mathematical model that connects ZGV decay rates with the fundamental attenuation coefficients. The methods were applied to determine the acoustic losses of aluminium and tungsten at low GHz frequencies.

References

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