Uncovering the True Attenuation of Silicon

High-Frequency Ultrasonic Measurements Accounting for Sound Field Effects

Type of Thesis: Diploma, master, bachelor, student thesis

Suitable for: Materials Science, Nanotechnology, Ultrasonics, Applied Physics

Motivation & Background:

Ultrasound is widely used in medical imaging and non-destructive material testing. The propagation of ultrasonic waves is affected by **frequency-dependent attenuation**, which occurs both in the coupling medium (e.g., water) and within the test material itself. Accurate knowledge of attenuation is critical for high-resolution imaging, acoustic metrology, and device characterization.

For **single-crystal silicon**, the attenuation at high frequencies (100–500 MHz) is still poorly characterized. Previous work attempted to measure attenuation using echo amplitudes from wafers and simplified diffraction models, but these measurements often **confound material attenuation with sound-field effects**, such as:

- beam focusing and diffraction
- multiple reflections inside the wafer
- standing wave resonances

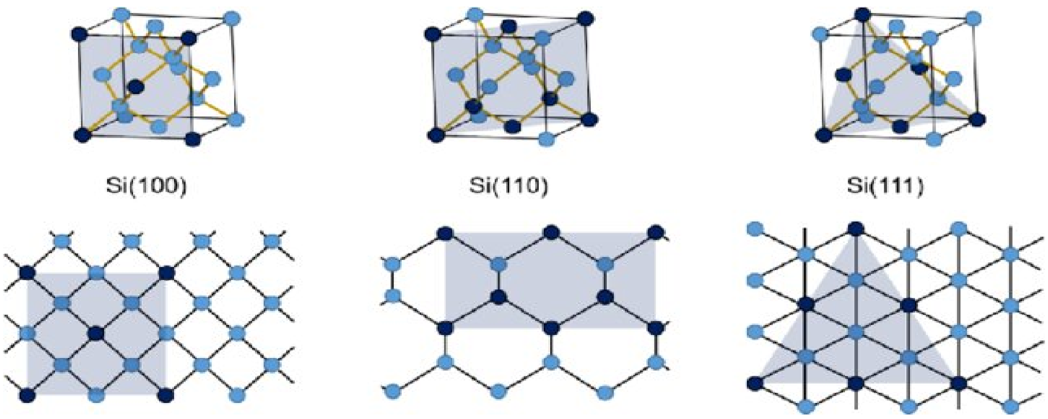

Figure 1: Silicon Cristall with Miller-Indicee (taken from https://doi.org/10.1021/acsomega.4c09272)

Furthermore, silicon is **elastically anisotropic**, meaning attenuation depends on crystal orientation (e.g., 001, 111). Most published results either ignore orientation or use polycrystalline silicon, limiting their applicability for semiconductor industry materials.

This thesis aims to **reliably measure the attenuation of single-crystal silicon** while explicitly **accounting for sound-field effects** using advanced modeling techniques. The results will provide fundamental material data critical for ultrasonics, MEMS, and high-frequency device applications.

Goals & Objectives:

The primary goal is to **determine the frequency-dependent attenuation of single-crystal silicon** for different crystallographic orientations while properly accounting for the ultrasonic sound field.

The work involves:

- Developing and applying a **sound-field model** for high-frequency transducers (Helmholtz-Huygens or Rayleigh diffraction integrals)
- Performing **experimental ultrasonic measurements** on silicon wafers with different thicknesses and orientations
- Extracting attenuation coefficients as a function of frequency by separating **material absorption** from **beam and diffraction effects**
- Preparing the results for **publication**, contributing improved and validated data for the scientific community

Milestones:

M1: Literature review on silicon ultrasonic properties, attenuation measurement techniques, and sound-field modeling methods.

M2: Development or adaptation of numerical sound-field calculations for the transducers used.

M3: Experimental setup of high-frequency ultrasonic measurement for silicon wafers.

M4: Data acquisition on wafers with different thicknesses and crystal orientations.

M5: Data processing and analysis, including separation of diffraction effects and calculation of true attenuation coefficients.

M6: Preparation of results for publication or thesis report.

Character of the work:

20 % Literature & Concept Development, 30 % Experimental Work, 30 % Data Evaluation & Characterization, 20 % Sound-Field Calculations

Supervision & Workflow:

- Meetings: weekly meetings between student and supervisor to evaluate status and progress and identify need for support; time and location (also possibly online) will be determined at the beginning of the work; additional meetings for any necessity are highly encouraged
- Lab works: The project pursues several works in the lab, which requires a reliable and structured workflow. Furthermore, the student will get a safety briefing for the house and the lab and the clean room.
- Weekly reports: The student is required to write a weekly report at the end of each week and to send it to his advisors or document it in git. The idea of the weekly report is to briefly summarize the work, progress, and any findings made during the week, to plan the actions for the next week, and to bring up open questions and points. The weekly report is also an important means for the student to get a goal-oriented attitude to work.
- Mid-term presentation: Students are encouraged to give a mid-term presentation as a preparation for the final presentation of the thesis. This is an opportunity to discuss the results with a broader audience and get important feedback on the current state of the work.

Technical Details:

- A **commercial Scanning Acoustic Microscope (SAM)** is available for performing high-frequency measurements on silicon wafers.
- **Single-crystal silicon wafers** with different crystal orientations (e.g., 001, 111) and thicknesses will be provided.

- An **existing simulation tool** is available, based on **generalized ray theory** and the **Willis method**, to model ultrasonic wave propagation and sound-field effects.
- A **server-PC** is provided for running the simulations and performing data analysis.
- The project combines **experimental measurements** with **advanced numerical modeling** to accurately separate material attenuation from beam and diffraction effects.
- Students will gain hands-on experience in **high-frequency ultrasonics, computational acoustics, and data analysis**.

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