LASERBASED ULTRASOUND FOR CHARACTERIZATION OF THIN FILMS AND MICROSTRUCTURES AND FURTHER APPLICATIONS

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The goal of most ultrasonic techniques is to obtain geometrical and/or mechanical information from structures in a non-destructive way. In order to achieve an acceptable resolution the wavelength of the acoustic pulses propagating through the media has to be short compared to the geometrical dimensions of the specimen. This condition becomes especially challenging when inspecting microstructures and thin films having sub-micron dimensions. Whereas the wavelengths used for the ultrasonic inspection of machine parts and airplane structures are in the millimeter range, the wavelength excited to analyze microstructures and thin films needs to be in the nanometer range. New experimental techniques are necessary because piezoelectrical devices typically cannot be used.

The so-called optical pump-probe technique was successfully adapted to perform ultrasonic measurements on sub-micron scales. In this technique two optical paths of variable length are used to precisely control the time shift between two synchronously emitted ultrashort laser pulses. Thus phenomena occurring on time scales shorter than the rise time of currently available photodetectors become accessible. Thermoelastically induced acoustic pulses are produced through the absorption of a femtosecond laser pump pulse. The acoustic pulse propagates perpendicular to the surface of a microstructure or thin film until it encounters a discontinuity in acoustic impedance causing the pulse to be partly reflected and partly transmitted. The reflected and/or the transmitted acoustic pulse cause a slight change of the optical reflectivity at the surface of the specimen, which is detected optically with an optical probe pulse. Thus the time of flight of an acoustic pulse and its pulse shape can be measured.

Experiments were successfully performed in different configurations on thin films and in different multilayer stacks, for instance in an aluminium-gold structure on a silicon oxide substrate. Furthermore mechanical properties of silicon nitride membranes and silicon cantilevers are determined by means of the measurement of picosecond ultrasound. In some materials like copper and gold the heat diffusion during the absorption of the ultrashort laser pulse affects the shape and the acoustic frequency spectrum of the propagating acoustic pulses. In these materials the acoustic wavelength is usually much higher (the frequency content much lower) than in aluminium for example. Since copper is of growing importance for chip manufacturers, who were among the driving forces of this measurement technology, the discussion of the detectability of very thin diffusion barrier layers (Ta, TaN) below a copper top layer is of great interest.

If mechanical pulses are excited in a structure which is tapered to a point these acoustic pulses can be focused to an extent that depends on the frequency spectrum of the acoustic pulse and the geometry of the structure. One application we studied concerned the focusing of acoustic pulses excited with ultrashort laser pulses inside silicon tips, which are often used in atomic force microscopes. An application of this technique as a transducer or in a new scanning probe method is conceivable.