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Methods for Material and Process Monitoring by Characterization of (Second and Third Order) Elastic Properties with Lamb Waves

Authors : R. Meier, M. Pander

Abstract : In accordance with the industry 4.0 concept, manufacturing process steps as well as the materials themselves are going to be more and more digitalized within the next years. The “digital twin” representing the simulated and measured dataset of the (semi-finished) product can be used to control and optimize the individual processing steps and help to reduce costs and expenditure of time in product development, manufacturing, and recycling. In the present work, two material characterization methods based on Lamb waves were evaluated and compared. For demonstration purpose, both methods were shown at a standard industrial product - copper ribbons, often used in photovoltaic modules as well as in high-current microelectronic devices. By numerical approximation of the Rayleigh-Lamb dispersion model on measured phase velocities second order elastic constants (Young’s modulus, Poisson’s ratio) were determined. Furthermore, the effective third order elastic constants were evaluated by applying elastic, “non-destructive”, mechanical stress on the samples. In this way, small microstructural variations due to mechanical preconditioning could be detected for the first time. Both methods were compared with respect to precision and inline application capabilities. Microstructure of the samples was systematically varied by mechanical loading and annealing. Changes in the elastic ultrasound transport properties were correlated with results from microstructural analysis and mechanical testing. In summary, monitoring the elastic material properties of plate-like structures using Lamb waves is valuable for inline and non-destructive material characterization and manufacturing process control. Second order elastic constants analysis is robust over wide environmental and sample conditions, whereas the effective third order elastic constants highly increase the sensitivity with respect to small microstructural changes. Both Lamb wave based characterization methods are fitting perfectly into the industry 4.0 concept.

Keywords : lamb waves, industry 4.0, process control, elasticity, acoustoelasticity, microstructure
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