Evolution of the Laser Flash Method for Bulk Materials to the Ultrafast Laser Flash Method for Thin Films by Pico/Nano Second Repetitive Pulsed Light Heating

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After the flash method was invented by Parker et al. in 1961, it was soon established as the reliable, standard and popular method for measuring thermal diffusivity of bulk materials. However, picosecond thermoreflectance method, which was invented by Paddock and Eesley in 1986, is still under progress and has not been established as the standard method to measure thermal diffusivity or thermal effusivity of thin films yet. One reason is incomplete data acquisition of optical delay technique as short as several nanosecond, which is less than half of the repetition pulse period of mode-locked lasers of longer than 12 ns. Another reason is that analytical equation has not been solved considering repetitive pulse heating and multi-layer analysis for thin films on substrate. Invention of electrical delay technique, which control trigger timing between two synchronized mode-locked lasers, realized complete acquisition of thermoreflectance signal over the repetition pulse period. Recently, we have solved exact analytical solution for one-dimensional heat flow across multi-layer thin films on substrate after repetitive pulse heating by Fourier expansion of thermoreflectance signal over the complete one period of repetitive heating. Thermal diffusivity and thermal effusivity of each layer of the thin film and boundary thermal resistance between successive layers are systematically determined by fitting the analytical solution to the observed signal over the period. Thanks to these breakthrough in apparatus and analysis, picosecond / nanosecond thermoreflectance methods can be now established as the standard method to measure thermophysical properties of thin films as reliable as the flash method for bulk materials. Now, it can be said that picosecond/ nanosecond thermoreflectance methods have been improved to "ultrafast laser flash method" from the view point that similarity of their geometrical configuration of signal observation, reliability of measurement and common approach of mathematical model and analysis to the laser flash method.