LOCALIZED DETECTION OF PHASE TRANSITION IN TUNGSTEN BY LASER ULTRASONICS

Z.N.Utegulov*[1], S.J.Reese[2], F.Farzbod[2], R.S.Schley[2], D.H.Hurley[2]

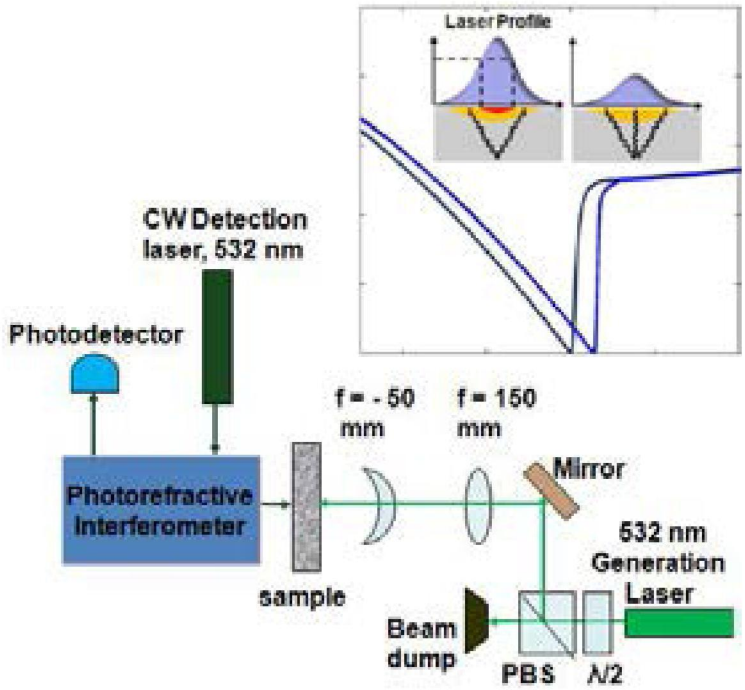
[1]Department of Physics, School of Science and Technology, Nazarbayev University, Astana, Kazakhstan;
*zhutegulov@nu.edu.kz; [2]Department of Material Science and Engineering, Idaho National Laboratory, Idaho Falls, Idaho, USA

INTRODUCTION.

Metal-to-liquid phase transition in refractory metals can be generated by pulse laser-irradiation of the surface. Short laser pulses can lead to surface heating, melting or evaporation. During laser-induced melting the molten mass loses its rigidity and the generation of the shear waves is significantly influenced by a shallow melt pool, while the propagation of longitudinal waves remains less influenced [1]. This work investigates the experimental and theoretical results on metal-to-liquid phase transition in tungsten generated by a nanosecond laser pulses and detected by two-wave mixing photorefractive interferometer. Proposed laser ultrasonics technique is envisioned for remote, nondestructive and localized post-irradiation examination (PIE) of thermo-physical properties of nuclear fuels. Due to laser-based nature of the method, this technique remote induces and senses phase transition in the solid material. Therefore, it is safe for any operator involved in PIE of nuclear fuels. Besides, the investigated method is furnace-free (i.e. containerless), circumventing furnace container-fuel interactions and material loss problems. Additionally, the proposed method is nondestructive for the entire investigated bulk sample since only sample surface is subject to laser irradiation. Investigated measurements are done on nanosecond time scale. They can also be spatially resolved due to localized interaction of laser irradiation with the sample. Also, a fundamental question about how ultrasonic waves are generated and evolved during solid-to-liquid phase transformation at fast time scales is explored. Also, laser ultrasonic studies in the regime of laser-induced melting are attractive because until now, most laser ultrasonic studies were conducted either in the regime of laser-induced mild heating or ablation, but not in the intermediate regime (i.e. melting).

MATERIALS AND METHODS.

An Nd:YAG pulsed laser operating at 532 nm was used to excite bulk ultrasonic waves. The sample under study consists of a thin pure polycrystalline tungsten plate. The broad surfaces of the sample were polished to a roughness < 20 nm and flatness of < λ/20. A photorefractive interferometer was used to detect out of plane surface motion associated with ultrasonic waves propagating along the epicentral direction. The generation laser pulse, recorded using 1 GHz photodetector, was used as the trigger to minimize time jitter in the recording of the temporal evolution of each waveform.



A beam splitter with known split ratio was used to determine the incident pulse energy of the generation laser. This energy was gradually increased up to 20 mJ. To study the dependence of laser induced melting and vaporization on laser peak power, two series of data were acquired corresponding to two incident laser beam diameters. For each data series the sample was translated to a fresh sample area. Waveforms were averaged 300 times to improve the signal to noise ratio. Typically, waveforms corresponding to the first two or three pulses looked different from the rest of the waveforms, likely due to laser ablation of surface contaminants. Based on the number of averages collected, the effect of these first few pulses is minimal. Shear arrival time was determined by fitting the waveform trough with a polynomial.

RESULTS AND DISCUSSION.

We detected onsets of melting and ablation by laser ultrasound. Shear waves are not sustained in a laser induced molten pool, causing a delay in their arrival time compared to an un-melted surface as seen in Fig. 1.

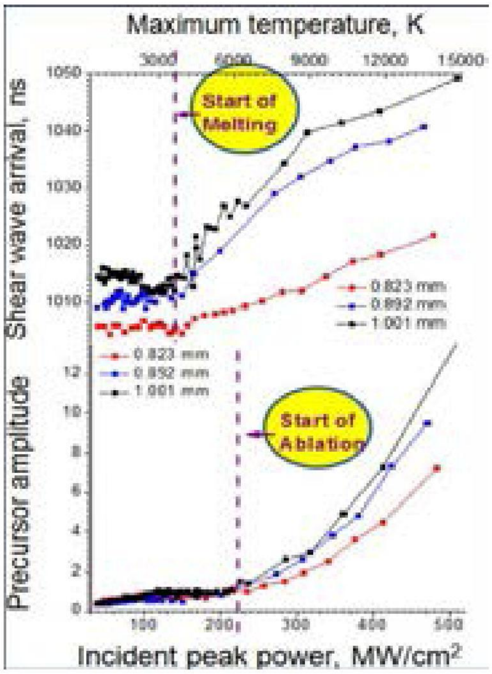


Figure 1. Laser induced heating, melting and ablation

showing rather abrupt delays of shear wave arrivals at the onset of melting. Characteristic increase in the amplitude of the signal associated with the arrival of longitudinal waves was attributed to the onset of ablation.

CONCLUSIONS.

We demonstrated a method for localized, furnace-free detection of the onsets of melting and ablation in polycrystalline tungsten using nanosecond laser ultrasonics. Pulsed laser-induced melting is characterized by a delay in the arrival of the shear wave with increasing laser peak intensity. Pulse-laser induced ablation was characterized by pronounced increase of the amplitude of the signal associated with the arrival of longitudinal acoustic wave. Both phenomena are attributed to a change in character of the ultrasonic source. The described technique suggests a new spatially resolved method for detection of metal-to-melt phase transition in refractory metals.

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