# Laser-Induced Plume and Keyhole Dynamics in Laser Welding

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## 1. Introduction

It is widely known that evaporation from the weld pool plays the most important role to achieve the deep penetration in laser welding. A deep keyhole is made by the recoil pressure of vaporization which is balanced with gravity head of molten pool and surface tensional pressure. A series of study is undertaken to obtain a fundamental knowledge of pulsed laser welding phenomena, especially evaporation mechanism of different aluminum alloys. In the previous works[1, 2], the authors have clarified the spectroscopic characteristics of laser-induced plume and the structure and composition of evaporated particles during pulsed laser welding of alloys containing a considerable amount of volatile elements. In this paper, the dynamics of plume and keyhole was investigated during pulsed YAG laser welding using high speed video photography and streak images. It was directly and simultaneously observed by high speed frame/streak camera using a special optical systems.

## 2. Material and Experimental Procedure

The aluminum alloy A5083 (4.58Mg-0.70Mn-0.12Cr) was chiefly used in this study, and then SUS304 (18.18Cr-9.15Ni) and pure Ti were utilized for comparison.

**Fig. 1** shows a schematic experimental setup for observation of plume and keyhole behavior. These were observed simultaneously by two high speed video cameras and a high speed streak camera. An argon ion laser beam was illuminated on the weld pool to obtain a direct image of the weld pool surface. The near-surface plasma emission background was decreased by using a narrow-bandwidth interference filter(FWHM:1nm) centered at the argon laser wavelength ($\lambda$=514.5 nm).

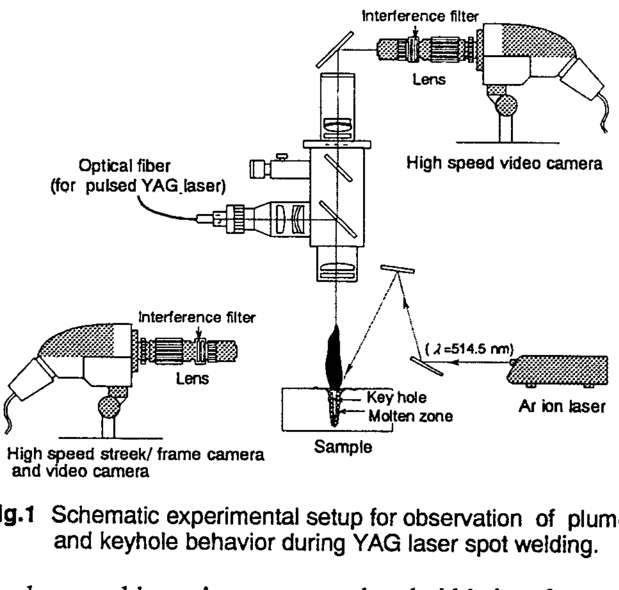


**Fig.1** Schematic experimental setup for observation of plume and keyhole behavior during YAG laser spot welding.

## 3. Experimental Results and Discussions

**Fig. 2** and **Table 1** show high speed streak images of laser-induced plumes and luminous plume propagation properties for different materials, showing periodic motion of plume. The conditions of high speed photography were with streak speed (*Vs*) of

86.12 mm/ms and temporal resolution ($R_t$) of about 1.16$\mu$s. The dynamic behavior of laser-induced plume was very unstable during the pulsed laser irradiation ($\tau_p$) of 7 ms, and its fluctuation period was about 450 $\mu$s for A5083. This instability was attributed to the evaporation phenomena of metals with different boiling points and latent heats of vaporization, and so on. These results were also recognized in **Fig. 3**, which were taken with a framing rate ($n_f$) of 40,500 f/s. **Fig. 4** shows high speed video pictures showing plume and keyhole behavior. Each framing photograph of a plume corresponds to that of keyhole respectively. The keyhole fluctuated in both size and shape, and the instability of keyhole was reflected to the plume behavior above the specimen surface. Especially, after laser termination, abrupt collapse of keyhole was closely related to the formation of porosity. That is to say, the dynamic behavior of laser-induced plume was closely related to the unstable motion of keyhole during laser irradiation, Therefore, the keyhole behavior in the molten pool can be estimated if the plume behavior is carefully observed and analyzed.

## 4. References


1) A. Matsunawa, J. D. Kim, S. Katayama and T. Takemoto : "Spectroscopic Studies on Laser Induced Plume of Aluminum Alloys", Proc.ICALEO'95 (San Diego), 1995 (at printer).
2) A. Matsunawa, J. D. Kim, S. Katayama and T. Takemoto : "Interaction between Laser Beam and Matter in Laser Welding (Report I ~ III)", The Review of Laser Engineering, The Laser Society of Japan, 1996 (to be published)


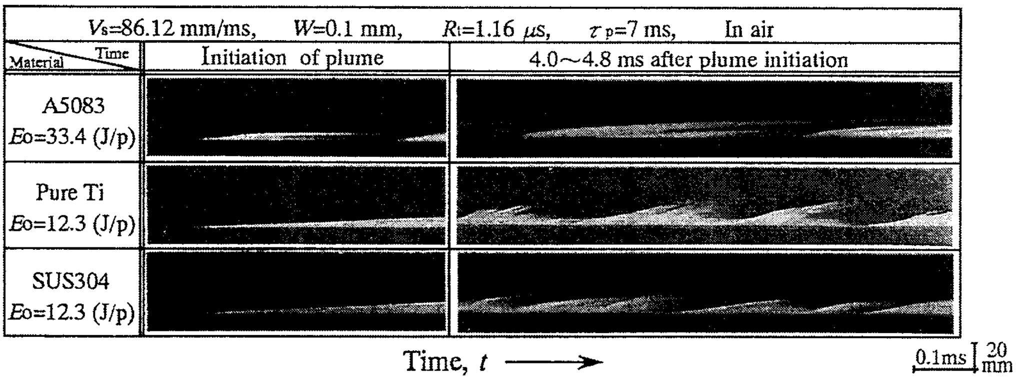


**Fig.2** High speed streak images of laser-induced plumes from different materials, showing periodic motion of plume.

Table 1 Luminous plume propagation properties for different materials

| | Propagation speed | | Periodicity ( 2.5 ~4 ms) |
|---|---|---|---|
| | Initial stage | Periodic motion | |
| A5083 | 5 m/s | 150~270 m/s | 450 $\mu$s(350~500 $\mu$s) |
| Pure Ti | 20 m/s | 100~170 m/s | 230 $\mu$s(210~320 $\mu$s) |
| SUS304 | 19 m/s | 60~170 m/s | 150 $\mu$s( 70~240 $\mu$s) |

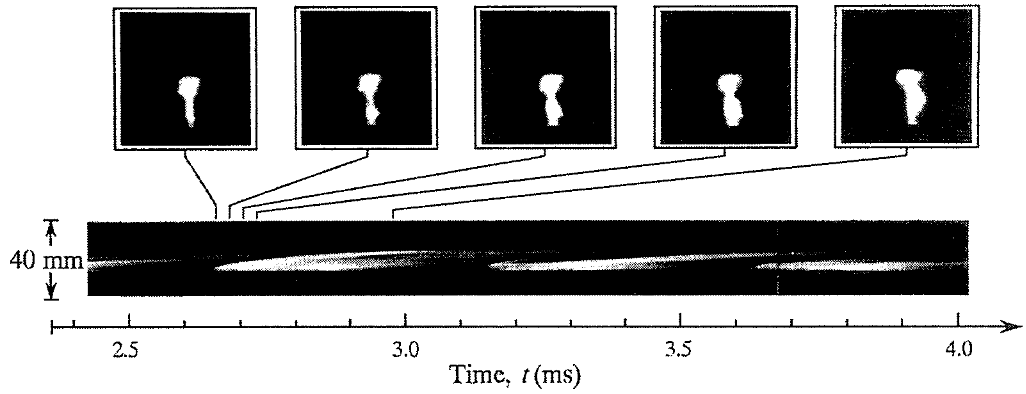


**Fig.3** High speed streak image and frame photographs of A5083 in air.
( $V_s$=86.12 mm/ms, $R_t$=1.16 $\mu$s, $n_f$=40,500 f/s, $\tau_p$=7 ms, $E_0$=28.7 J/p )

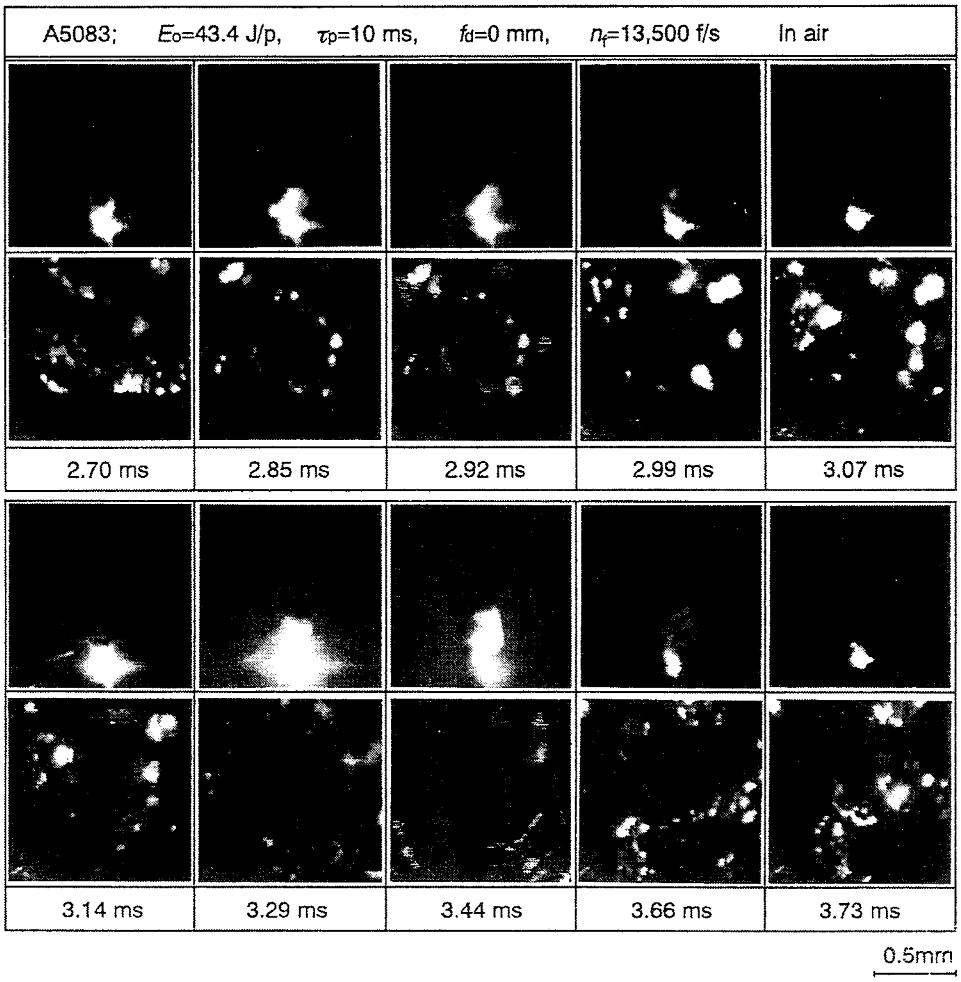


**Fig.4** High speed video pictures showing laser-induced plume and keyhole behaviors during pulsed YAG laser irradiation.