The "Golden" Laser Spark Plug Assembly Process

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Abstract: The Solderjet Bumping technique has been used to assemble by soldering means the optical components of a laser spark-plug ignition device, hence guaranteeing high robustness and space compatibility devices. The laser could deliver pulses with adjustable energy between 4.70 mJ and 2.40 mJ and duration around 0.8 ns, thus being suitable for inducing air breakdown phenomenon.

1. Introduction

It is now well known that laser ignition (LI) can bring several advantages in comparison with ignition done by classical electrical spark plugs [1]. Thus, there is no quenching effect of the combustion flame kernel; the laser beam can be delivered at any point within the combustion chamber; ignition can be obtained simultaneously at different positions inside the cylinder, or LI can fire lean air-fuel mixtures. A CO_2 laser was used by Dale et al. in 1978 to operate, for the first time, a one-cylinder ASTM-CFR engine [2]; furthermore, LI of a four-cylinder Ford Mondeo engine was first achieved by Mullet et al. in 2008 [3] with Nd:YAG lasers. Based on the development of compact laser spark plugs [4,5] similar to classical spark plugs, LI was successfully applied to operate real vehicles, by T. Taira et al. in 2013 [6] and in 2015-2017 by N. Pavel et al. [7,8]. Advantages of LI were also demonstrated in natural gas engines [9], as well as in aeronautical or aerospace applications [10].

Laser ignition devices require compact and miniaturized designs, which in addition have to guarantee operation in extreme conditions (like vibrations, shocks and high temperatures). To achieve this, we designed and assembled a laser spark plug using the low-stress soldering technique Solderjet Bumping (Fig. 1a). This technique applies a localized input of thermal energy, using a laser pulse to reflow, melt and place soft solder alloys onto different materials. In this way, brittle materials as those used for lenses, can be soldered to the device housing without damaging the components. This process requires creating of metallic wettable surfaces over the optical components. Such a metallic interface (Fig. 1b) is applied by physical vapor deposition (PVD) [11].

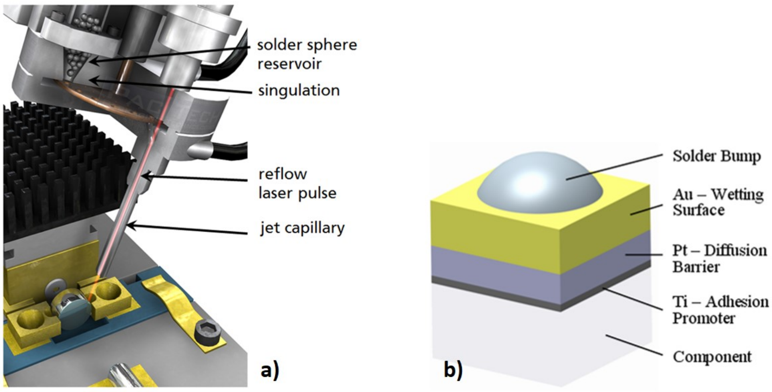

Fig. 1. **a)** Schematic of Solderjet Bumping bondhead. **b)** Schematic of three applied layers (Ti/Pt/Au) to create a wettable surface over components to be joined.

2. Device design and assembly process

The lenses of the present laser spark plug were inserted and later soldered to independent stainless-steel frames; all components have been later put into the stainless-steel main body (as shown in Fig. 2). The optical components have been locally metalized (Ti/Pt/Au layers where applied on the edges of the lenses keeping thus, the proper dimension of the clear aperture) to allow light transmission, while the stainless-steel frames and the main body have been fully metalized. The Nd:YAG/Cr^{4+}:YAG ceramic was placed between copper frames for a better heat removal.

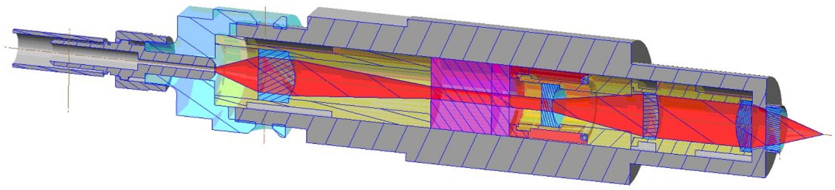

Fig. 2. Lenses frames and the Nd:YAG/Cr^{4+}:YAG ceramic medium (pink) inserted into the stainless-steel main body. Laser beam propagation is shown in red.

The laser pulse energy of the Solderjet Bumping bondhead used to reflow, melt and finally solder the lenses was about 450 mJ. For the lenses, several spherical droplets of 300 µm diameter (Fig. 3a) have been used around the perimeter with an equal spacing (60° in the case of six droplets), which guarantees enough robustness of each laser spark plug internal part [12]. In order to prevent fuel from being inserted into the device, the sapphire window has been soldered using few-hundred droplets of 300 µm diameter that were continuously applied along the window perimeter (Fig. 3b, c).

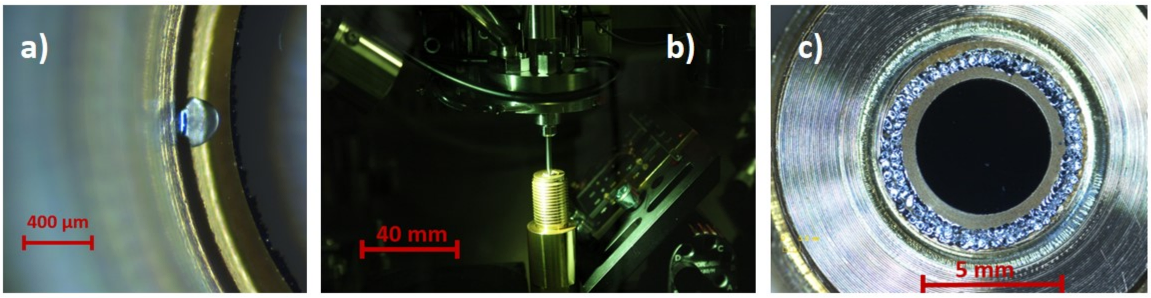

Fig. 3. **a)** Detail of applied bump between the lens edge and the stainless-steel mount. **b)** The soldering process of the sapphire window. **c)** Detail of the continuously soldered sapphire window onto the stainless-steel frame.

3. Results

A final laser ignition spark plug has been assembled. Interesting, as the device body and lenses have been initially metalized with Au layers using a PVD sputtering technique, a final unusual golden color for the laser spark plug was obtained (Fig. 4a). These Au layers have been used to create a wettable and solderable surface onto the optics and the stainless-steel bodies. The laser device yielded, by slightly adjustments of the pump line, pulses with energy between 4.70 mJ and 2.40 mJ and duration around 0.8 ns; the maximum pump pulse energy at 807 nm was 44.2 mJ. Air breakdown realized with such a laser spark plug delivering pulses with 2.80 mJ energy is exemplified in Fig. 4b.

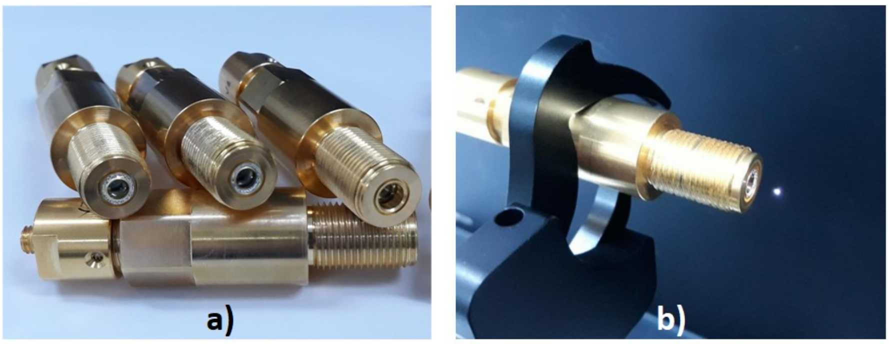

Fig. 4. a) Several “golden” laser spark plugs are shown. **b)** Air breakdown produced by the 2.80 mJ laser pulse.

4. Conclusions and outlook

As a new approach, a laser ignition spark plug device has been mounted using the Solderjet Bumping technique. The device yielded similar laser pulse performances as the ones in which the optical components were fixed by glue [7, 13]. For the first time, such devices have been designed and assembled with this method, guaranteeing high robustness [14], materials and space compatible processes [15] while avoiding damage or induced birefringence on the optical components [16-17].

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