EPJ Web of Conferences **26**, 01022 (2012)
DOI: 10.1051/epjconf/20122601022

Interferometric windows characterization up to 450 K for shock wave experiments: Hugoniot curves and refractive index

E. Fraizier, P. Antoine, J.-L. Godefroit, G. Lanier, and G. Roy

CEA, DAM, Valduc, 21120 Is-sur-Tille, France

Abstract. Conventional shock wave experiments need interferometric windows in order to determine the equation of state of a large variety of metals. Lithium fluoride (LiF) and sapphire are extensively used for that purpose because their optical transparencies enable the optical diagnostics at interfaces under a given range of shock pressure. In order to simulate and analyse the experiments it is necessary to gather a correct knowledge of the optical and mechanical properties of these windows. Therefore, our window supplies are systematically characterized and an experimental campaign under shock loading is conducted. Our preliminary work on LiF windows at 532 nm is in good agreement with literature data at room temperature and the new characterization at 450 K enables a better interpretation of our preheated target experiments. It confirms the predominant effect of density on optical properties under pressure and temperature. The present work demonstrates that the initial density determination is a key point and that the uncertainties need to be improved. For that purpose, complementary experiments are conducted on LiF windows with simplified target designs and enriched diagnostics, coupling VISAR (532 nm) and PdV (1550 nm) diagnostics. Furthermore, a similar campaign is conducted on sapphire windows with symmetric impact configuration.

1 Challenges for the LiF characterization

Traditional shock wave experiments need windows to characterize a variety of materials. Lithium fluoride (LiF) along [100] axis is extensively used for that purpose because it remains optically transparent until more than 100 GPa. In order to analyse and simulate the experiments it is necessary to have a good knowledge of the optical and mechanical properties of these LiF windows. This in mind it is necessary to characterize our windows supply: density, crystalline orientation, acoustic velocity and geometrical measurements. A preliminary campaign [1] was conducted in order to characterize the behaviour under dynamic loading in particular at 450 K which is the selected temperature level for our preheated system [2]. The present work presents a simplified target configuration with a PDV diagnostic (1550 nm).

2 Experimental program

Under classical impact configuration the optical diagnostics measure the velocities at the interfaces (Fig. 1). In particular, one channel of the PDV diagnostic enables to measure the impact velocity and the velocities at both interfaces of the window.

First of all, the shock wave time of flight Δt_{LiF} is measured and knowing the thickness e_{LiF} of the LiF window, the shock wave velocity U_S is calculated (1)

$$U_S = \frac{e_{LiF}}{\Delta t_{LiF}} \tag{1}$$

Secondly, relations from literature [3–6] allow determining the optical corrective index $n_0 - \lambda$ from the ratio of the apparent velocity gap Δu_a (when the shock emerges at the free surface) and the velocity at the free surface u_{FS}

$$k = n_0 - \lambda - 1 = \frac{\Delta u_a}{u_{FS}} \tag{2}$$

The actual particle velocity u_p at the interface is consequently determined by

$$u_p = \frac{u_a}{n_0 - \lambda} \tag{3}$$

To go further, the Rankine-Hugoniot relations are applied. The pressure is then calculated and the shock density is expressed as a function of the initial density ρ_0, the shock velocity U_S and the particle velocity up:

$$P = \rho_0 U_S u_p \tag{4}$$

$$\rho = \rho_0 \frac{U_S}{U_S - u_p} \tag{5}$$

Finally, the refractive index is determined as a function of density (6)

$$n = n_0 - \lambda + \lambda \frac{\rho}{\rho_0} \tag{6}$$

The experimental configuration is minimalist: a flyer (Cu or W) and a 3 mm thickness LiF window (Fig. 1). Usually, an optical treatment (OT) is applied on the LiF windows to minimize the reflections at 1550 nm. However the PDV system demonstrates very interesting capabilities because the measurements remain possible with this treatment. Nevertheless two experiments without this optical treatment are carried out to maximize the signal measured at the window interfaces. A powder gun is used to conduct the experimental campaign (Table 1) and the shock pressure ranges from 5 to 20 GPa. The LiF supplies (from BFI OPTILAS Company) are characterized and the following values were obtained:

- [100] for the crystalline orientation,
- 2.630 for the density at 300 K,
- $\alpha = 3.990 \times 10^{-11} \times T^2 + 5.125 \times 10^{-8} \times T + 3.225 \times 10^{-5}\ \mu$m.m^{-1}.°C^{-1} for the linear thermal expansion along the [100] axis,
- 6396 m.s^{-1} for the longitudinal acoustic velocity along the [100] axis.

Table 1. Experimental campaign.

Name / OT @ 1550 nm	Flyer (thick. / metal)	Impact velocity (m/s)	Shock pressure (GPa)
# 02 / yes	2.8 mm/Cu	1062	12.4
# 03 / no	2.8 mm/Cu	1579	19.8
# 06 / yes	2.8 mm/Cu	1395	17.2
# 08 / yes	5.0 mm/Cu	1259	15.1
# 11 / yes	4.2 mm/W	948	13.1
# 17 / yes	2.8 mm/Cu	912	10.3
# 18 / no	2.8 mm/Cu	1470	18.2
# 19 / yes	2.8 mm/Cu	486	5.3

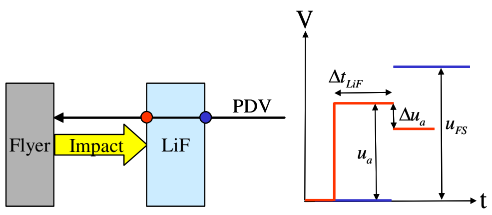

Fig. 1. Principle of the experiments.

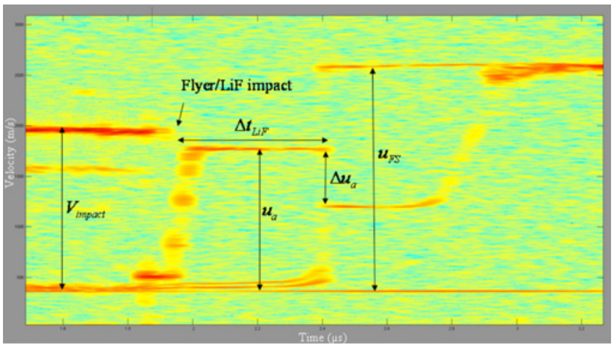

Fig. 2. PDV measurements for the interface velocities.

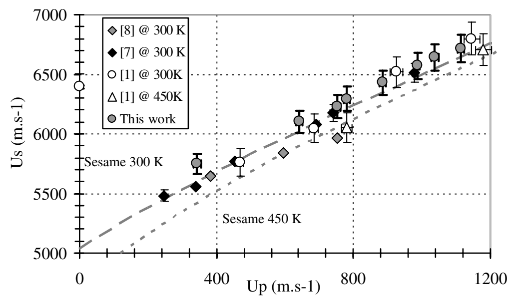

Fig. 3. Shock velocity as a function of particle velocity.

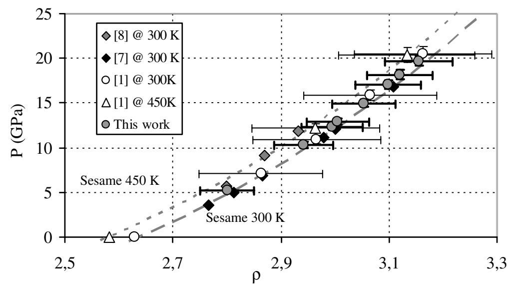

Fig. 4. Shock pressure as a function of density.

3 Experiment analysis

This part illustrates the analysis of one of the PDV results (Fig. 2) recorded at the interfaces. The first analysis consists in the measurement of the shock time of flight Δt_{LiF} through the window. The shock velocity is calculated, knowing the thickness of the LiF window.

Then, the velocity plateau and the velocity gap when the shock merges at the free surface are measured. Furthermore, the free surface velocity is also measured and the relation (2) is applied in order to determine the corrective index. Finally, the Rankine-Hugoniot relations enable to calculate the shock pressure, density and refractive index (4–6). Some values are directly measured from diagnostics giving their experimental uncertainties: it is the case for the windows thickness, the time of flight and the apparent velocities for examples. The other values are calculated from relations (1–6). In this case, two simple rules (7) and (8) are applied

$$\frac{\Delta(a \times b)}{a \times b} = \frac{\Delta(a/b)}{a/b} = \frac{\Delta a}{a} + \frac{\Delta b}{b} \tag{7}$$

$$\Delta(a+b) = \Delta(a-b) = \Delta a + \Delta b \tag{8}$$

for the uncertainty calculation and propagation. So, with experimental uncertainties of roughly 1% the calculated values reach more than 3%.

4 Experimental results

Fig. 3 shows the shock velocity (1) as a function of the particle velocity (2–3). Our results are compared to the literature data at room temperature. They show in good agreement with [7] but show strong deviation from [8]. Furthermore, the SESAME data (dashed lines) are consistent with our uncertainty level.

To go further, the pressure and density are calculated (Fig. 4) with the relations 4 and 5. The uncertainties are 3% for the shock pressure and 2% for the density. These results serve some remarks to emphasize that the initial density is a crucial parameter for the LiF characterization. Indeed,

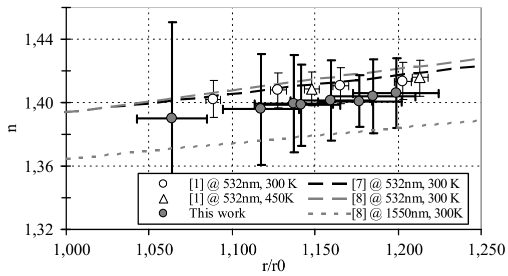

Fig. 5. Refractive index as a function of the normalized density.

ρ_0(T) is an input data to calculate the shock pressure, the shock density and the refractive index (4–6). So, it is noticeable that the literature references use a 2.641 initial density at room temperature [7, 8] which is different from our 2.630 measurement. The refractive index is then calculated from the relations (2) and (6) and knowing the no=1.3827 measured for $\rho = \rho_0$. Furthermore, the density is normalised with the initial density ρ_0(T) corresponding to the initial temperature of the experiment.

These results (Fig. 5) confirm the Jensen [8] observations: at 1550 nm the refractive index is lower than for the 532 nm optical diagnostics. It confirms the theory that the refractive index is a function of wavelength and density. A linear fit taking our uncertainties into account is achieved:

$$n = (1.2709 \pm 0.3695) + (0.1117 \pm 0.3168)\,\frac{\rho}{\rho_0} \qquad (9)$$

5 Conclusions

This new campaign conducted on LiF windows at 1550 nm with a PDV diagnostic is in good agreement with literature data at ambient temperature. These diagnostic presents interesting capabilities for the windows characterization. Indeed, the velocities are measured at different interfaces with or without optical treatment of the windows surfaces. Furthermore, this simple target configuration could enable the windows characterization during classical shock wave experiments conducted on different metals. Taking into account the initial temperature through the initial density, our results confirm the theory that the refractive index is a linear function of the normalized density ρ/ρ_0 and the wavelength dependence is confirmed.

Improvements on the uncertainties are necessary and possible in the future with other experimental configurations and diagnostics optimizations (time and velocities). A further study is planned to measure directly the density as a function of temperature. Indeed, the LiF has a crystalline orientation and the application of the linear expansion (isotropic approximation) could be discussed and improved in future work.

A similar campaign is planned for the shock and optical (at 532 and 1550 nm) characterization of sapphire windows. Furthermore, a new preheating apparatus is under development to reach 800 K and give the opportunity (or necessity) to conduct the windows characterization at higher initial temperature.

References

1. E. Fraizier, et al., New Models and Hydrocodes for Shock Wave Processes in Condensed Matter 2010.
2. G. Roy, et al., J. Phys. IV **134**, (2006).
3. L. Barker, and R.E. Hollenbach, J. Appl. Phys. **41**, (1970).
4. E.U. Condon, and H. Odishan, Handbook of Physics, (1958).
5. D.R. Goosman, J. Appl. Phys. **65**, (1989).
6. J. Wackerle, H.C. Stacy, and J.C. Dallman, Pro. Inst. Soc. Opt. Eng (SPIE) **832**, 72 (1987).
7. B.M. Lalone, O.V. Fat'yanov, J.R. Asay, and Y.M. Gupta, J. Appl. Phys. **103**, (2008).
8. B.J. Jensen, D.B. Holtkamp, P.A. Rigg, D.H. Dolan, J. Appl. Phys. **101**, (2007).