Laser and Particle Beams (2001), *19*, 237–239. Printed in the USA.

Accurate timing of a particle beam using laser ablation

A. BALLARD AND K. BONIN
Department of Physics, Wake Forest University, Winston-Salem, N.C. 27109

(RECEIVED 11 August, 2000; ACCEPTED 9 December, 2000)

Abstract

We report on a new technique that we used to accurately time the velocity of a cluster beam. It involves deflecting particles away from their usual beam path by scattering with an ablation plume. We were able to time the occurrence of a C_{60} cluster beam to better than 0.2%. This technique was critical in recent light-force polarizabilities experiments.

Keywords: Beam timing; Laser ablation; Particle beam

1. INTRODUCTION

We report on a technique we have used for timing a neutral particle beam to high accuracy. This result grew out of a set of experiments for measuring the optical polarizability of C_{60} clusters (see Ballard *et al.*, 2000). The development of this method to accurately time the particle beam was critical to the success of our experiments. The technique is simple to describe, easy to implement, works for both neutrals and ions, and has a number of advantages over other methods.

The basic timing problem we are trying to solve is this: A beam of neutral particles is generated at an initial point and they traverse a moderately long beam path (2.5 m) at the end of which they are ionized. The particle beam consists of a pulse that extends for about 14 cm in space and the ionization process only affects a small "slice" that is about 3 mm wide. We need to know the time when the particles pass a certain point, labeled P, that lies along the beam path (see Fig. 1). This would be solved if the velocity were accurately known. Our technique can be used to get the particle velocity. The problem in our case is that the particles do not leave the source at a precisely known time. Our source is a cluster seeded helium gas source like that of Haufler *et al.* (1991) and the dwell time of the clusters in the source can vary by 35–100 μs, depending on source conditions.

Address correspondence and reprint requests to: K. Bonin, Department of Physics, Wake Forest University, Winston-Salem, NC 27109, USA. E-mail: bonin@wfu.edu

2. ALTERNATIVE METHODS

One solution is to put a velocity selector in the vacuum. A selector made of a series of large, thin disks (with slots) on a common axis (with at least one of them rotating) is a traditional solution (e.g., see the early work on velocity measurements of a cadmium beam by Eldridge, 1927, and see the discussion by Ramsey, 1956). In a recent experiment to settle the question of the temperature of a cluster beam, Bucher *et al.* (1990) chopped out a 10-μs portion of their pulsed, supersonic cluster beam. In our case, this would correspond to about a 3 cm slice, which is an order of magnitude coarser than our ablation technique. Another possibility is a fast electromechanical shutter. However, the fastest shutters have rise and fall times of 500 μs for very small shutter apertures (1–2 mm) and so for a typical beam experiment, where the traversal time is up to a few milliseconds, this does not adequately isolate the slice of particles with enough fineness. Another possibility is a pulsed nozzle. The gas released would provide a sudden transverse impulse to the cluster beam and deflect it away from the ionization region. The very fastest valves can operate in the 50-μs range and so you can get the beam scattered to within 5%. This is far coarser than we needed and the gas load to the vacuum system presented by such a solution is too large for our beam line.

Another avenue might be to ionize the desired particle slice with a pulsed laser and send the beam through a pair of metal plates. A potential across the metal plates would de-

https://doi.org/10.1017/S0263034601192128 Published online by Cambridge University Press

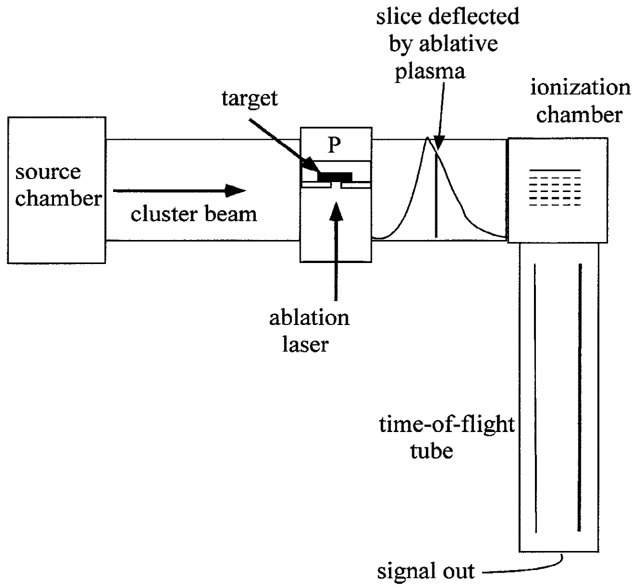

Fig. 1. A sketch of the experimental apparatus. The beam travels 2.5 m from the source to the point of ionization. The TOFMS is 1.3 m long. Ablation of the target into the particle beam occurs about 80 cm before the ionization point.

flect the ions into the wall. We did not have enough intensity, nor the correct wavelength, to ionize our particle beam. The vertical extent of the particle beam was 4 mm, so a tightly focused laser would not intersect most of the beam.

3. ABLATION METHOD AND DISCUSSION

Our technique is to rapidly inject a plasma into the particle beam at a right angle to deflect the appropriate slice of the beam. The injected plasma can be rapidly and cleanly formed by focusing a pulsed laser onto a solid target to initiate ablation. To ablate the graphite target, we used the fundamental wavelength (1.064 μm) of an unfocused pulsed Nd:YAG at typical laser energy of about 200 mJ. The pulse width of our Nd:YAG laser is about 7 ns (full-width at half-maximum). In our case, we produced a narrow region of ablated material by placing glass slides over a graphite target to mask all but a small portion of the target for laser ablation. The ablating target was placed 2–3 mm from the beam and the ablation and expansion process occurs so rapidly that we could determine the time our particle slice passed in front of the target to within 1 μs (out of 1.15 ms). The main disadvantage here is that nearby vacuum surfaces are lightly coated with graphite. However, steps can be taken which minimize the deposition. The main advantages are the rapid response of the ablation process and the ability to very accurately control the timing of the ablation by controlling the pulsed laser timing. In Figure 2 we show the typical curves produced by detecting the particle beam after ionization and deflection down a time-of-flight mass spectrometer (TOFMS). The three different curves demonstrate the removal of particles from the beam path as the time of laser ablation is varied. The timing can be understood as follows: If the laser ablation pulse occurs

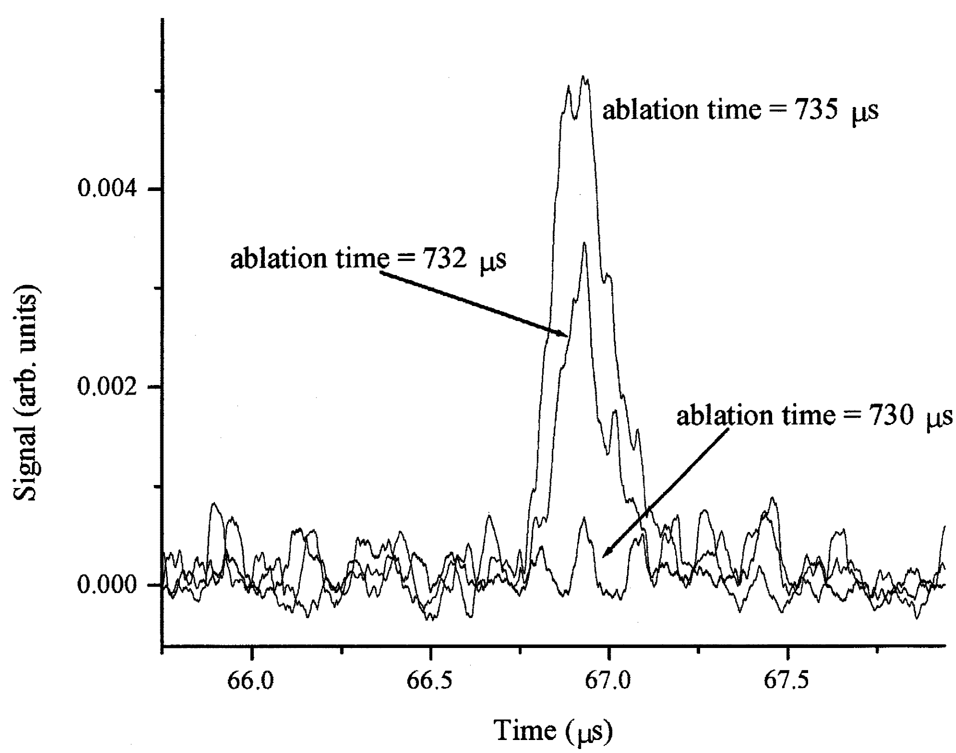

Fig. 2. Intensity of the C_{60} cluster beam for different delays in ablation from a graphite target into the C_{60} beam. These curves correspond to having the ablation target in the cluster source about 1.5 m from the exit of the supersonic nozzle.

https://doi.org/10.1017/S0263034601192128 Published online by Cambridge University Press

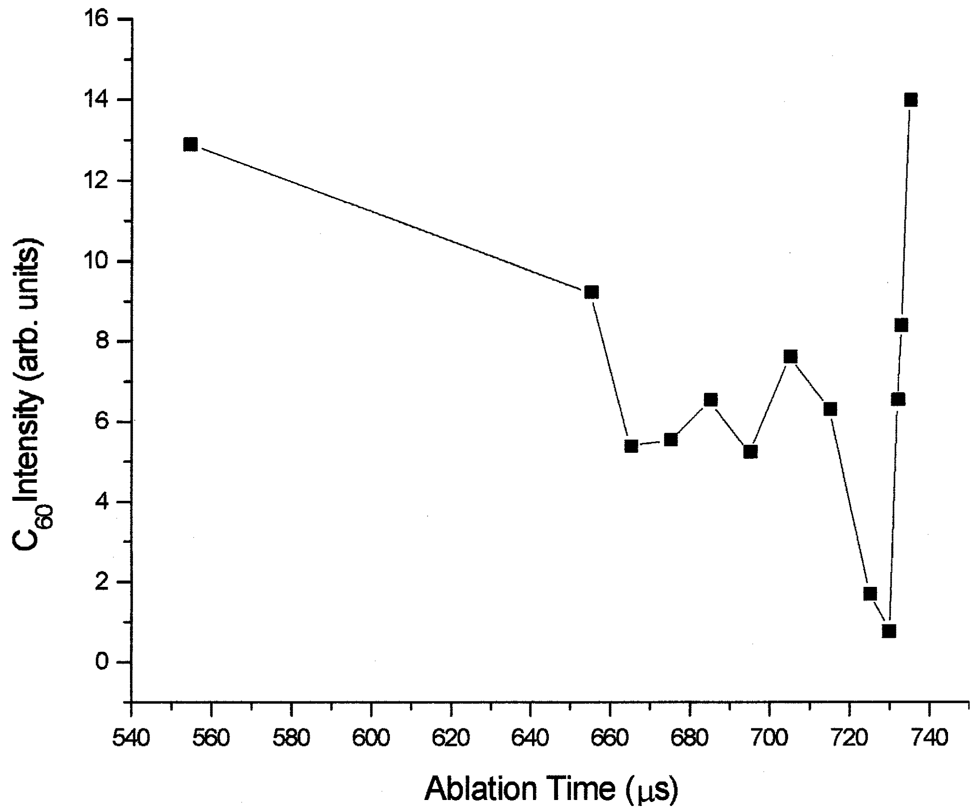

Fig. 3. Scattering of the C_{60} cluster beam by the ablative products from a graphite target. Note the abrupt transition at 731 μs. In 2 μs, the signal goes up by more than a factor of eight. See Figure 2 for some of the raw data curves near the abrupt transition time.

before the appropriate particle slice passes by point P, then the beam intensity will be reduced. This will be true as the time delay is increased. Eventually the cluster beam intensity will reach a *minimum* when the appropriate beam slice is directly in front of the target during ablation. Further delay in the time of occurrence of the ablation pulse will cause a sharp rise in intensity because the appropriate slice has already passed through the region and the ablated plasma cannot affect it.

Figure 3 demonstrates this timing very effectively. This curve was taken with the ablation target at point P in Figure 1. Here the beam intensity is plotted as a function of ablation time. An abrupt change in intensity is visible at 731 μs. In 5 μs, the curve has gone from minimum intensity to peak intensity, a change of a factor of 20. The minimum intensity stands out very clearly, and in this way, we were able to pinpoint the time needed to apply a light-force laser to a beam of C_{60} clusters to measure their polarizabilities. The time measured by our ablation technique was within 2 μs of the time we actually observed an effect due to our light-force laser. Determining this timing so accurately was crucial. A side benefit was that we know the velocity of that particular slice to about 0.5%. This is obtained from the ablation deflection time, the time of ionization with the excimer pulse, and the distance between these two points. The velocity value was used as an input to the fitting programs of our polarizability measurements.

To conclude, we have demonstrated the utility of a simple laser ablative technique for accurately determining the timing and velocity of a neutral particle beam. The data are easy to interpret and reproducible.

ACKNOWLEDGMENTS

The authors are thankful for support from Wake Forest University and from the National Science Foundation (Contract No. 9420441). We also thank Lou Bloomfield and Joe Louderback for helpful discussions.

REFERENCES

Ballard, A., Bonin, K. & Louderback, J. (2000). Absolute measurement of C_{60} polarizability. *J. Chem. Phys.* **113**, 5732–5735.

Bucher, J.P., Douglass, D.C., Xia, P. & Bloomfield, L.A. (1990). A pulsed supersonic expansion with a source temperature below 100 K. *Rev. Sci. Instrum.* **61**, 2374–2377.

Eldridge, J.A. (1927). Experimental test of Maxwell's distribution law. *Phys. Rev.* **30**, 931–935.

Haufler, R.E., Wang, L.-s., Chibante, L.P.F., Conceicao, J., Chai, Y. & Smalley, R.E. (1991). Fullerene triplet state production and decay: R2PI probes of C_{60} and C_{70} in a supersonic beam. *Chem. Phys. Lett.* **179**, 449–454.

Ramsey, N.F. (1956). *Molecular Beams*. Oxford: Oxford University Press.