

Glass slits for collimating particle beams

A. Ballard and K. Bonin

Department of Physics, Wake Forest University, Winston-Salem, North Carolina 27109

(Received 29 August 2000; accepted for publication 4 December 2000)

We report here on the construction and use of a pair of matched glass collimating slits which are suitable for molecular beam work. These glass slits transmit nearly all ($>85\%$) of an incident laser beam. Additionally, these slits are matched to better than $5\text{--}10\ \mu\text{m}$ at a gap size of $200\ \mu\text{m}$.

© 2001 American Institute of Physics. [DOI: 10.1063/1.1344600]

I. INTRODUCTION

The scientific goal of our experiments that require glass slits is the measurement of alternating current polarizabilities of clusters. To measure ac cluster polarizabilities, we need to generate and collimate a dense beam of cold clusters. The glass slits reported here were critical in our ability to generate and collimate this beam. For example, these slits made possible our recently reported measurements of the polarizability of C_{60} .¹ The purpose of this article is to describe the design, construction, characterization, and performance of these glass slits.

Molecular beams are typically collimated by a pair of well-aligned metal slits along the molecular beam axis (e.g., see Ramsey's book).² However, we need to collimate particles along a well-defined axis as well as counterpropagate focused laser light along the same axis—see Fig. 1. Laser light must be counterpropagated down the cluster beam axis in order to generate cold clusters using a supersonic laser ablation source.

Supersonic cluster sources based on the design proposed by Kantrowitz and Gray³ were attempted in the early 1950s by Kistiakowsky and Slichter.⁴ A few years later, Becker and Bier⁵ successfully achieved the high molecular beam intensities predicted by Kantrowitz and Gray.³ An interesting description of the early history and development of supersonic nozzle beams is given by Anderson.⁶ The earliest seeded supersonic sources were oven pickup sources, where the material to be cooled was generated in an effusive oven and injected into a channel along with a high pressure of carrier gas, for instance helium. Here, collisions with the carrier gas serve to cool and, in the case of clusters, condense the material. This mixture is then forced through a narrow throat and expanded supersonically into vacuum. Almost any material, including refractories, can be cooled and condensed into clusters through the use of laser ablation. Much of the work in laser ablation supersonic cluster sources was pioneered by Smalley and co-workers in the early 1980s.⁷ Here the important difference is the replacement of the effusive oven with laser ablation of a target consisting of the desired material. Early experiments were done with a single-valve, side ablation source.⁸ In this implementation, the target material enters the source in a direction orthogonal to the final direction of the cluster beam. Many investigators^{9–11} have used intense, cold particle beams to investigate various

physical properties of clusters. More recently, a dual-valve source was designed by Smalley and co-workers¹² to produce even more efficient cluster cooling. In this source, material is ablated along the direction of the molecular beam—see Fig. 1. Two opposing gas jets increase the local gas density at the ablation point (higher than that of the single-valve source) and thereby increase the amount of collisional cooling for the newly ablated clusters. This source has been shown to provide higher densities of clusters on-axis, as well as a marked decrease in cluster temperatures. Note that this source requires focusing the ablating laser light over $1\text{--}2\ \text{m}$ so that the focal plane is within about $10\ \text{cm}$ of the target (and close to slit No. 1 in Fig. 1).

Needing to make use of the higher cluster density and cooler temperatures made possible by the dual-valve source, we began to investigate the amount of laser light transmitted along the cluster beam axis with traditional metal slits. We found that before even a modest fluence of $200\ \text{mJ}/\text{cm}^2$ of laser light could be passed through the pair, the metal slits began to be damaged. Most laser ablation experiments require a fluence of at least that amount, so clearly traditional razor slits are not suitable for the task.

We report a slit design which easily transmits more than $400\ \text{mJ}/\text{cm}^2$ per pulse from a $532\ \text{nm}$ yttrium–aluminum–garnet (YAG) laser with a $7\ \text{ns}$ pulse width without any visible damage to the slits. The construction of these slits proved pivotal in a recent polarizability measurement.¹

II. DESIGN/CONSTRUCTION

A pair of matched glass slits were made, with the design as shown in Fig. 2. The glass slits are shown in the diagram so that it is easy to observe the polished edge of the slit touching the carefully ground slit wall. The actual slit holders had mounting holes near the corners that are not shown in Fig. 2. These holes are omitted from the diagram because their size/location is irrelevant to the design and were specific to our implementation. Also note that the overall dimensions depicted in Fig. 2 were suitable for our implementation of the slit holder. For the slit holder it is critical to carefully grind the slit wall and to carefully deburr all machined/ground surfaces. Also key is that the slit wall actually drops below the surface of the holder as shown in Fig. 2. In our experiments, the two slit assemblies were separated by $1\ \text{m}$, and each assembly was mounted on transverse rails, so each

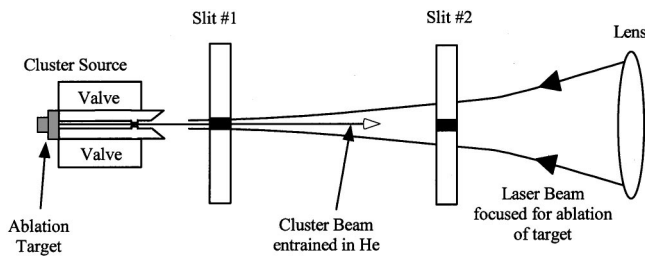


FIG. 1. A sketch of the experimental apparatus. A solid target is ablated by absorbing the light pulse from a Nd:YAG laser (frequency doubled to produce 532 nm light). The laser light is incident from right to left in the figure, and must pass through both of the slits to reach the target. Ablated particles from the target are then mixed with helium gas and then must travel from left to right in the diagram, passing through the two slits.

slit position could be adjusted and so each slit could be moved out of the way to allow a larger number of clusters to be temporarily transmitted for setup and calibration purposes.

All dimensions of the slit holder were carefully cut to their respective dimensions on a milling machine with the exception of the slit wall (see Fig. 2). The slit holder was removed from the milling machine when the slit wall had 5 mil (0.005 in.) of material left on either side. At this point, the pair of slit holders were moved to the grinder where the precision edge was ground.

The slits themselves were the real challenge. The slits are constructed using edge-polished microscope cover slips. The ablation laser light was frequency-doubled Nd:YAG at a wavelength of 532 nm. The laser rep rate was 10 Hz and the

laser's pulse width was 7 ns, so we needed to identify a material that could pass a reasonable fluence of at least 300–400 mJ/cm² and retain a clean and straight edge. Different plastics were tried with varying degrees of success. The more promising of these were clear poly vinyl chloride (PVC) (which damaged at 100 mJ/cm²) and clear Plexiglas (which damaged at 110 mJ/cm²). Also, we tried various plastic sheets (such as mica and acetate) but these damaged (melted, formed color centers, etc.) at even lower fluences (about 99 mJ/cm²) or were unable to hold an acceptable edge. After these investigations, we concluded that only glass could pass enough light and maintain useful edge quality.

A common source of thin glass available in the laboratory is microscope cover slips. These proved useful, but careful examination of the normal “from the factory” edge revealed many rough edges and microcracks. Attempts were made to polish the edges one at a time, but the cover slips proved too fragile and we subsequently polished the slips in lots of 75 or more. Since cover slips are quite inexpensive, this was a reasonable approach. Though breakage occurred, there were still many usable cover slips from each batch. Cover slips prepared in this way were used in our experiments. In addition, we were able to have a similar stack of cover slips commercially polished to $\lambda/2$.

The slit edges produced “in house” were polished using a homemade jig on a milling machine. The polishing jig consisted of a 1/2 in. aluminum plate 6 in. in diameter. A short rod was attached to the center and a cylindrical cover-slip holder was attached to the outer edge of the disk. Beginning with open coat sanding papers of 600, 1200, 2000, and 2500 grits, the cover slips were rid of all rough edges and gouges. Extensive polishing was done with a polishing slurry of cerium oxide and a polishing pad affixed to the bed of the milling machine. Slips for the holder were selected on the basis of a careful examination of the edge under a (20 \times) microscope.

Selected slips, cleaved to the appropriate dimensions by use of a diamond-tipped pen, were carefully attached to the slit holder with vacuum epoxy. After assembly, contact of each slit with the holder edge was carefully checked along its length before, during, and after the epoxy cured.

III. PERFORMANCE

Final evaluation was done by measuring the diffraction pattern of each slit using a 10 mW helium–neon laser beam. The pattern produced by each set of slits on their holder was compared to the pattern produced from a razor blade slit set on the same holder. Information gathered from this analysis pointed out any problems that might force us to reject that particular slit. Problems such as curvature, uneven gap, or chipped/frayed edges were easily identified by this means. Also, the diffraction pattern was used to provide us with a precise measurement of the width of the slit. Various matched and mixed slit sets were made, with the mixed set used in the actual experiments having measured gaps at $202 \mu\text{m} \pm 3 \mu\text{m}$ and $259 \mu\text{m} \pm 3 \mu\text{m}$. A typical pair of matched slits, ground in tandem, were measured to match to better than 5–10 μm .

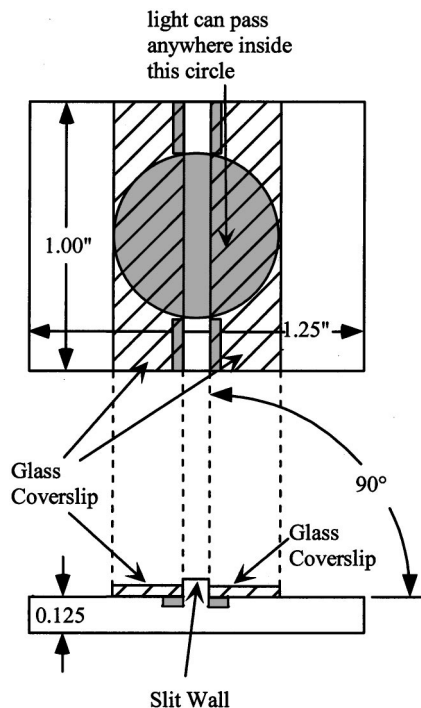


FIG. 2. Precision ground flat slit. Note that the hole (shaded gray) has a diameter of 0.625 in., the slit wall height is 0.007 in. above the top of the base, and the width of the slit wall is 0.009 in. These labels have been omitted for the sake of clarity. The glass slits (crosshatched objects) are glued to the slit holder and one edge of each glass piece is made flush against the slit wall (see lower figure).

The glass slits described here were critical in our ability to generate and collimate a suitably dense, cold beam of C₆₀ clusters for polarizability experiments. The cluster beams were well-collimated by these glass slits—in particular, the spatial distribution of the clusters was close to that expected from theory.¹

ACKNOWLEDGMENTS

The authors thank Wake Forest University and the National Science Foundation (contract No. 9420441) for their support. In addition, the authors are grateful to Carolina Industrial Sales (Clemmons, NC) for their assistance and supply of abrasives.

- ¹A. Ballard, K. Bonin, and J. Louderback, *J. Chem. Phys.* **113**, 5732 (2000).
- ²N. Ramsey, *Molecular Beams* (Oxford University Press, New York, 1956).
- ³A. Kantrowitz and J. Grey, *Rev. Sci. Instrum.* **22**, 328 (1951).
- ⁴G. Kristiakowsky and W. Slichter, *Rev. Sci. Instrum.* **22**, 333 (1951).
- ⁵E. Becker and K. Bier, *Z. Naturforsch. A* **9**, 975 (1954).
- ⁶J. Anderson, *Molecular Beams and Low Density Gas Dynamics* (Marcel Dekker, New York, 1974), pp. 1–91.
- ⁷T. Deitz, M. Duncan, D. Powers, and R. Smalley, *J. Chem. Phys.* **74**, 6511 (1981).
- ⁸P. Milani and W. de Heer, *Rev. Sci. Instrum.* **7**, 1835 (1990).
- ⁹L. Bloomfield, M. Geusic, R. Freeman, and W. Brown, *Chem. Phys. Lett.* **121**, 33 (1985).
- ¹⁰W. de Heer, P. Milani, and A. Châtelain, *Z. Phys. D: At., Mol. Clusters* **19**, 241 (1991).
- ¹¹W. de Heer, P. Milani, and A. Châtelain, *Phys. Rev. Lett.* **63**, 2834 (1989).
- ¹²R. Hauffer, L.-S. Wang, L. Chibante, J. Conceicao, Y. Chai, and R. Smalley, *Chem. Phys. Lett.* **179**, 449 (1991).