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Experimental Observation of Resonance Effects in Intensely Irradiated Atomic Clusters

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Abstract. We have resolved the expansion of intensely irradiated atomic clusters on a femtosecond time scale. These data show evidence for resonant heating, similar to resonance absorption, in spherical cluster plasmas.

1. Introduction

There have been many studies of the irradiation of atomic clusters with short pulse high intensity laser radiation [1-4]. The high local density of cluster targets greatly increases the coupling of the laser energy to the atoms. Recent experiments [1,4] have examined the dynamics of cluster disassembly. Of particular interest is the time for disassembly and the heating mechanisms involved. Theory [3] predicts resonance effects should play a major role in these interactions. Similar to resonance absorption, this resonance should greatly enhance the absorption of laser energy by the clusters. Due to the spherical geometry of the clusters, the resonance occurs when the electron density is three times the critical density. In this paper we report on a series of experiments investigating these resonance effects

2. Experimental Methods

The laser used for these experiments was a Ti:Sapphire CPA laser system operating at a wavelength of 810 nm, capable of producing about 50 mJ in a 50 fs pulse [5]. We could vary the laser pulse length by changing the grating spacing in the compressor. The beam could also be directed through a beamsplitter, with one beam going into a variable delay leg. The beam was then focused with an f/3 off axis paraboloid onto a cluster target. The clusters were produced by expansion in a supersonic Laval nozzle backed with up to 200 psi of xenon. From a calculation of the Hagena parameter we estimate the average number of atoms per cluster, N, to be up to 6×10^5 [6,7]. The cluster radii ranged from 85 Å to 205 Å. The average density produced by the nozzle is estimated to vary from approximately 1.5×10^{17} to 6×10^{17} atoms/cm^3 [8].

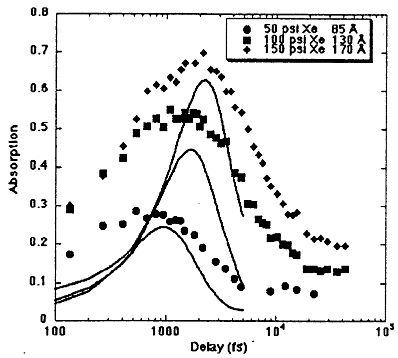

Fig. 1. Data from the pump probe experiments. Solid lines are model calculations.

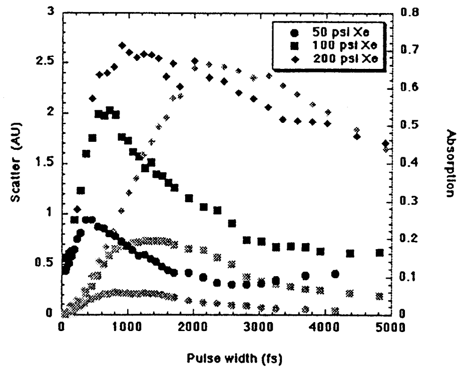

Fig. 2. Absorption (black) and Mie scattering (gray) measurements. Note that they peak for different pulse widths.

3. Results and Discussion

In the pump-probe experiments a small (10%) pump pulse was sent into the target to expand the clusters before the probe pulse arrives. This allows us to probe the disassembly of the clusters as they expand into a bulk plasma. Both pulses were about 50 fs in length. The probe pulse had a peak intensity in vacuum of 1.6 x 10^{17} W/cm^2. Figure 1 shows absorption as a function of probe delay for different backing pressures of xenon. The absorption peak in Fig. 1 indicates the presence of resonant heating as the clusters expand. At very small delays, absorption is low; the cluster has little time to expand and the second pulse arrives long before the electron density reaches the resonance condition ($n_e/n_{crit}=3$). However, as we increase the delay, absorption increases. The longer delay allows the electron density to be near the resonance condition when the pulse arrives, greatly enhancing the absorption of laser light. For longer delays, the cluster has continued to expand and the probe pulse is poorly absorbed by the, now underdense, plasma. Eventually, we reach a condition in which the clusters are fully disassembled and the absorption approaches a constant depending only on the average gas density. Our model, similar to Ref. [3], is shown as solid lines in Fig 1. The delay for peak absorption is in good agreement with the data.

Figure 2 shows that results of a simultaneous measurement of absorption and 90° Mie scattering of the laser radiation for different pulse lengths. Clearly the scattering signal reaches a maximum at a longer pulse length than the absorption. As a cluster expands, not only does the electron density decrease, but the radius increase as well. For spheres of the relevant size, the ratio of scattering cross section to absorption cross section increases as radius increases [9]. This should cause the observed increase in scattering after the absorption has reached it peak

4. Conclusions

In conclusion, we have resolved the expansion of atomic clusters on a femtosecond time scale. These data show that spherical resonance absorption plays an important role in cluster heating. The effects of resonance is seen in Mie scattering measurements also. However, the peak in the scattering occurs for longer pulse widths than absorption measurements.

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References

1. T. Ditmire, E. Springate, J. W. G. Tisch, Y. L. Shao, M. B. Mason, N. Hay, J. P. Marangos, M. H. R. Hutchinson, Phys. Rev. A 57, 369 (1998).
2. J. Purnell, E. M. Snyder, S. Wei, A. W. Castleman Jr., Chem. Phys. Lett. 229, 333 (1994).
3. T. Ditmire, T. Donnelly, A. M. Rubenchik, R. W. Falcone, M. D. Perry, Phys. Rev. A 53, 3379 (1996).
4. M. Lezius, S. Dobosz, D. Normand, M. Schmidt, Phys. Rev. Lett. 80, 261 (1998).
5. P. Banks, J. Zweiback, S.N. Fochs, B.C. Stuart, M.D. Perry, in Conference on Lasers and Electro-Optics, Vol 9 1996 OSA Technical Digest Series (Optical Society of America, Washington, DC, 1996), paper CWI3.
6. O. F. Hagena and W. Obert, J. Chem. Phys. 56, 1793 (1972).
7. J. Wörmer, V. Guzielski, J. Strapelfeldt, T. Möller, Chem. Phys. Lett. 159, 321 (1989).
8. M. D. Perry, C. Darrow, C. Coverdale, J. K. Crane, Opt. Lett. 17, 523 (1992).
9. M. Kerker, The Scattering of Light and other Electromagnetic Radiation, (Academic Press, New York, 1969).