Irradiation effect of hot electronic beams on parylene films postprint

Authors: Yanbin Wang, CHEN Zhimei, CHANG Guanjun

Date: 2023-06-18T00:00:00+00:00

Abstract

The multi-layer parylene (PP) films were irradiated by hot electrons with a dose of 2$×$1016 cm 2. The irradiated and non-irradiated films have been examined by FT IR, UV-Vis and strain-stress measurement instruments. The results show that the damage has been created for irradiated films, including benzene rings and broken C-C bonds. The absorbance on the vision light increases and the Yang's modulus decreases greatly in irradiated films with the worse toughness. The experimental conditions determine whether these effects hinder hydrodynamic instability or not.

Full Text

Preamble

Irradiation Effect of Hot Electron Beams on Parylene Films

WANG Yanbin*, CHEN Zhimei, CHANG Guanjun
The Research Center of Laser Fusion, CAEP, Mianyang 621900, China

Abstract
Multi-layer parylene (PP) films were irradiated by hot electrons with a dose of 2$×10^{16}$ cm^{-2}. Both irradiated and non-irradiated films were examined using FTIR, UV-Vis spectroscopy, and tensile testing instruments. The results show that irradiation creates damage in the films, including disruption of benzene rings and broken C-C bonds. The absorbance in the visible light range increases, while the Young's modulus decreases significantly and the toughness deteriorates in irradiated films. Whether these effects hinder hydrodynamic instability depends on the experimental conditions.

Keywords
Irradiation chemistry, Hot electron irradiation, Parylene

Introduction

ICF (inertial confinement fusion) experimental results are strongly influenced by instability development, which is an important phenomenon in many physical processes [1,2]. In designing physical experiments and preparing targets, various factors that may induce instability must be analyzed to restrain it within acceptable limits. The origins of instability in ICF experiments include laser imprinting, target symmetry, surface roughness, and internal defects in the target [3,4]. It has been demonstrated that all these inevitable sources of instability in the early stages of physical experiments can be controlled.

However, other types of instability sources produced during the explosion process—such as the effect of hot electron beams generated in the hohlraum or corona region of the target irradiating the shell, the effect of penetrating hard X-rays on target structure, and the effect of ultra-fast ions on surface and subsurface layers—have been less studied. These processes are closely linked to energy deposition and implosion, and their associated instability can be masked by instabilities from other undesirable factors such as initial experimental conditions and target defects, making it difficult to isolate the instability from these specific processes. To further study these explosion physics problems, it is necessary to investigate the instability resulting from irradiation of the target shell by hot electrons and hard X-rays during the explosion process.

Additionally, the pulse width in hohlraums is on the nanosecond scale, and the electron beam intensity in ICF experiments reaches 10^{16}–10^{18} cm^{-2} [5], which cannot be achieved with ordinary accelerators. Therefore, thermal electron damage experiments under these parameters are rarely performed.

Currently, the preferred target shell materials for ICF experiments are Be(Cu), CH(Ge,Si), and C(diamond) [6,7]. Among these, CH-based shells are the most technically feasible. In this paper, we simulate the damage effects of hot electrons on target shell thickness and the influence of hot electron energy range on the shell, using parylene (PP) samples with a C:H ratio of 1:1. We also study the structure and state of materials prior to the ablation starting point to provide accurate instability factors for further investigation of instability phenomena in ICF explosion experiments.

2 Experimental

The experiment was performed using an accelerator at Sichuan University. The output electron beam intensity at the accelerator port was 2$\times$10^{12}$ cm^{-2} · s^{-1}, with a beam scanning area of 100 cm × 100 cm. The single electron energy ranged between 1.75 MeV and 1.8 MeV, with a 37 mm air gap between the vacuum chamber exit and the sample. An electron energy of 1.75 MeV was adopted for calculations of single electrons incident on the sample.

As shown in Fig.1, a copper sheet with a thickness of 0.462 mm was placed in front of the sample to attenuate the electron energy to the hot electron energy

range. The samples, measuring 25 mm (length) × 25 mm (width) × 35 m (thickness), were prepared via chemical vapor deposition and stacked in multiple sheets. The total thickness exceeded the electron range in PP after passing through the copper sheet. As shown in Fig.1, the accumulated irradiation dose of thermal electrons was 2$×10^{16}$ cm^{-2}.

Both irradiated and non-irradiated samples were studied using FTIR (Fourier Transform Infrared Spectroscopy), UV-Vis (Ultraviolet-Visible Spectroscopy), and tensile testing instruments. PP films penetrated by hot electrons and non-irradiated films were selected for analysis. FTIR measurements were performed using a NICOLET 6700 system in absorption mode, with a resolution of 4 cm^{-1} and wavenumber range of 400–4000 cm^{-1}. UV-Vis measurements were performed using a Perkin Elmer Lambda 12 system in transmission mode, with a resolution of 1 nm and wavelength range of 300–1000 nm. Tensile measurements were performed using a KD series WDT-10 model instrument.

3 Monte Carlo Calculations of Electronic Stopping Power

The two-body collision approximation is used to handle the multi-body collision problem between electrons and target ions/electrons [8]. Since energy loss induced by target electrons is much greater than that caused by the nucleus, material damage is primarily caused by energy loss to target electrons. Monte Carlo methods were used to calculate electron incidence on PP material, with results shown in Fig.2.

In the hot electron energy region of interest, the energy loss per unit path length of incident electrons shows an approximately linear decrease on a logarithmic coordinate. The electron range is 63.5 m and 25.8 m for energies of 100 keV and 60 keV, respectively. Longitudinal straggling increases with range, reaching a proportion as high as 1:2. The lateral straggling radius also increases with range, with a proportion to longitudinal straggling that can reach 1:1.

4 Results and Analysis

Non-irradiated samples were colorless and transparent, while irradiated samples turned yellow and opaque, indicating the formation of chromophoric groups in the irradiated material. PP material contains only two elements (C and H) and two types of groups (methylene and benzene ring). Chromophoric groups likely result from precipitation of carbon elements or formation of new groups.

To investigate the chemical state of PP material after 100 keV hot electron irradiation, samples penetrated by 100 keV electrons (according to Monte Carlo calculations) were selected for FTIR analysis, as shown in Fig.3. The chemical groups in parylene contain only methylene and benzene rings, making the spectrum relatively simple. Absorption peaks appear near 2853 cm^{-1} and 2922 cm^{-1} for symmetric or asymmetric stretching vibrations of methylene, near 3016 cm^{-1} for C-H stretching on benzene rings, and at 1064 cm^{-1} and 1452 cm^{-1} for

skeletal deformation vibrations of benzene rings [9].

Comparison of non-irradiated and irradiated samples reveals no shift in absorption peaks, nor the appearance of new peaks or disappearance of original peaks. However, the intensity of several characteristic peaks changes: peaks at 1452 cm^{-1} and 3016 cm^{-1} (benzene ring) and 2853 cm^{-1} and 2922 cm^{-1} (methylene) show reduced amplitude in irradiated samples, while peaks at 1604 cm^{-1} (benzene ring) and 1697 cm^{-1} (carbonyl group) show increased amplitude.

UV-Vis spectroscopy was performed on two samples to characterize their light absorption properties. As shown in Fig.4, light absorption in the UV-Vis range increases after irradiation, and the cutoff wavelength shifts to longer wavelengths. This yellowing suggests the presence of free carbon elements and other chromophoric groups, consistent with FTIR measurements and visual observation. This effect may help reduce preheating of the fusion fuel.

Tensile testing was used to measure changes in mechanical properties. Results are shown in Fig.5, where (a) represents the non-irradiated sample and (b) the irradiated sample. The non-irradiated sample curve (a) exhibits three segments: Segment I with sharp stress increase, Segment II with smooth stress variation but large strain variation, and Segment III with sharp stress drop to zero. The irradiated sample curve (b) shows only two segments: Segment I with sharp rise and Segment III with sharp drop, lacking the platform segment (simplified as a turning peak). The maximum stress is 26.67 MPa/cm^2 for the non-irradiated sample but only 4.36 MPa/cm^2 for the irradiated sample. The strain rate is 12% for non-irradiated samples but drops to less than 0.4% for irradiated samples.

FTIR results show that valence bond breaking occurs in PP material under intense hot electron irradiation, inevitably producing internal defects and increasing the material's energy state. This helps increase the ablation speed of the target shell. The increased absorbance at 1604 cm^{-1} indicates formation of benzene-like material during hot electron passage, analogous to heavy ion irradiation of PP material [11].

Although energy loss increases at the end of the hot electron range, FTIR results show minimal material damage there, because some electrons are absorbed during transmission, reducing the total number reaching the end. The enhanced peak at 1697 cm^{-1} in irradiated samples is attributed to a small amount of oxygen attaching to the surface during irradiation, forming carbonyl groups.

5 Discussion

When used as target shell material in hohlraums, PP functions to confine fusion fuel, absorb energy, and compress the fuel [10], requiring high material quality. Simulation results show that 100 keV hot electrons can penetrate approximately 35 m of PP material. After irradiation damage occurs, the fusion fuel is heated by the deposited energy, which can reach dozens of keV, increasing compression difficulties.

Tensile test data indicate that the Young's modulus of irradiated PP films decreases significantly, mechanical strength deteriorates sharply, and the bearable strain rate becomes smaller, meaning the toughness of irradiated material deteriorates. These changes are undesirable for ICF target shell materials that must withstand certain pressures. For instance, if the initial pressure is too high, the film may crack and allow encapsulated fuel to escape—a phenomenon that must be absolutely prevented during ICF experiments.

References

1. Park H S, Lorenz K T, Cavallo R M, et al. LLNL-JRNL-413702, 2009.
2. Watari T, Nakai M, Azechi H, et al. Phys Plasmas, 2008, 15: 092109.
3. Smalyuk V A, Hu S X, Goncharov V N, et al. PRL, 2008, 101: 025002.
4. Goncharov V N. PRL, 1999, 82: 2091–2094.
5. Dewald E L, Suter L J, Thomas C, et al. First hot electron measurements in near-ignition scale hohlraums on the national ignition facility, LLNL-PROC-419391, 2009.
6. Clark D S, Haan S W, Hammel B A, et al. Phys Plasmas, 2010, 17: 052703.
7. Haan S W, Herrmann M C, Amendt P A, et al. Fusion Sci Technol, 2006, 49: 553–557.
8. Ziegler J F. J Appl Phys/Rev Appl Phys, 1999, 85: 1249–1272.
9. Xu C, Shen J, Zhou B, et al. J Sol-Gel Sci Technol, 2008, 45: 319–324.
10. Jeffrey Atherton L. Targets for the national ignition campaign, UCRL-CONF-234395, 2007.
11. (Reference incomplete in original)

Note: Figure translations are in progress. See original paper for figures.