様式9

論文審査の結果の要旨

<table>
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学位論文題目

Theoretical and Application Researches on Gas Breakdown and Spark Evolution by Laser Irradiation

レーザー誘導ガスブレイクダウンとプラズマ生成に関する理論と応用研究

審査結果の要旨

レーザ光で誘起されるプラズマ現象は，レーザ誘起ブレークダウン法やレーザ着火などの分野で利用されてきている．本現象は，対象ガスの温度を常温から数万度に数ナノ秒で変化させる物理現象を含み，レーザ光と物質との相互作用，高温下での化学反応など，複雑な物理現象を含み，従来の方法では理論的な解析が困難な領域であった．本研究では，多光子イオン化，プラズマによる光の吸収，プラズマの膨張などの現象をlattice Boltzmann method（LBM）を用いて解析した．本解析法より，多光子イオン化による電子生成，レーザ光による電子の加速並びに電子衝突イオン化によるプラズマの成長が解析可能となった．また，本結果をレーザ誘起ブレークダウン法に適用し，減圧下において電子衝突イオン化を抑えることにより，ヨウ素の高感度計測が可能なことを実証した．

以上，本研究は，レーザ光で誘起されるプラズマ現象を解析的に可能とする新しいコンセプトの解析技術を提案すると共に，その結果をレーザ誘起ブレークダウン法に適用して実験的検証を提示するものであり，本論文は博士（工学）の学位授与に値するものと判定する。

様式7

論　文　内　容　要　旨

報告番号	甲　先　第　197　号	氏　名	張　小波
学位論文題目	Theoretical and Application Researches on Gas Breakdown and Spark Evolution by Laser Irradiation レーザー誘導ガスブレイクダウンとプラズマ生成に関する理論と応用研究		

内容要旨

Laser-induced gas plasma has gained substantial interest during the past decade due to its potential industrial applications, such as laser-induced breakdown spectroscopy, laser ignition, laser propulsion, etc. This thesis is mainly concerned the simulation of laser energy deposition, the resultant fluid dynamic evolution in gas by the energy spot as well as gas plasma used in laser-induced breakdown spectroscopy technology for element trace.

Chapter 1 states the brief introduction to laser-induced gas plasma as well as its related industrial application technologies. The previous numerical and experimental researches are also summarized to show the purpose of study in this thesis.

Chapter 2 theoretically describes processes of plasma generation by laser irradiation as well as the resultant hydrodynamic evolution: initial release of feed electrons by multiphoton ionization, ionization of gas in the focal region of the laser beam by cascade ionization, absorption of laser energy by gaseous plasma, rapid expansion of the plasma and detonation formation within laser pulse, and the propagation of pressure wave into the surrounding gas after laser pulse.

In chapter 3, propagation of pressure wave caused by laser energy disposition in argon are numerical studied. A model about Nd:YAG laser energy deposition in argon has been developed for this purpose. It is designed to predict the fluid dynamic effects of the energy deposition process in quiescent argon. The key physical processes are captured, including evolution of energy spot shape and structure, ionization and recombination chemical reactions, evolution of the pressure wave front and the subsequent fluid movement.

To simulate the propagation of the laser beam in time, the Maxwell equations and the finite difference time domain method are adopted. The discretization process of Maxwell equations, disposal of boundary conditions and the incident wave in FDTD are discussed in detailed in chapter 4. At last the Gaussian beam, which is

usually used for a specified form of the laser beam, is simulated by FDTD.

In chapter 5, the gas kinetic theory and the continuous Boltzmann equation are firstly introduced. To solve the continuous Boltzmann equation, the lattice Boltzmann method (LBM) is adopted. The build-up processes of D2Q9 as well as the universal numerical procedure of LBM are discussed in detailed. After the background knowledge, gas plasma produced by laser irradiation is modeled by Boltzmann equations.

In chapter 6, interaction of laser and existing plasma as well as generation of gas plasma by laser irradiation is simulated by a hybrid model. Maxwell equations, which are used to model the propagation of laser, are calculated by the finite difference time domain method. Employing coefficients of distribution functions, processes of multiphoton ionization, electron impact ionization and three-body recombination are included in Boltzmann equations. Using D2Q9 model in LBM, number densities of particles in plasma can be obtained after solving Boltzmann equations. For the energy transformation in plasma, the finite volume method is applied to calculate the macroscopic energy equations directly coming from the continuous Boltzmann equations.

As one important application of gas plasma produced by laser irradiation, laser-induced breakdown spectroscopy technology for iodine detection is studied in chapter 7. Iodine in buffer gases of N2 and air was detected using nanosecond and picosecond breakdowns of CH3I at reduced pressure. The measurement results of iodine demonstrated that low-pressure LIBS is the favorable method for trace species measurement in analytical application. The plasma generation process can be controlled by the gas pressure and laser pulse width for the larger ionization and excitation processes of iodine, which is discussed by the intensity ratio of iodine emission at 183 nm to nitrogen emission at 174.3 nm. The detection limit of iodine measurement in N2 was 60 ppb in nanosecond breakdown at 700 Pa. Iodine in the buffer gas of air was also detected using nanosecond and picosecond breakdowns to discuss the effect of oxygen.

Chapter 8 is the summary and conclusion of this thesis as well as some suggestions for future research.