# Development of Measurement Method for Warm Dense Matter toward Material Selection for Fast Ignition

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## ABSTRACT

To survey the optimum materials for fast ignition, we have introduced approaches by using pulsed-power experiment. To evaluate the electrical properties of warm dense matter (WDM) for insulator as a diamond-like –carbon (DLC), we have developed exploding wire compression method by using pulsed-power discharge. The results show that the voltage and current waveforms with and without coating DLC are different after the wire ablation. From the absorption spectroscopic measurement, the DLC temperature is estimated to be 9000 K. We have developed a two-dimensional magnetohydrodynamics code for understanding process of the strong magnetic field. The results indicate that the electrical conductivity of wire affects the generated magnetic field distribution. From above experimental and numerical approaches, WDM properties are important to select material for fast ignition.

## Keywords

Warm Dense Matter, Alternative Fast Ignition, Diamond-like-carbon, Laser Capacitor Coil Target, Electrical Conductivity

## 1. Introduction

Critical to fast ignition [1] is the transport of the laser-generated fast electrons and their associated heating of compressed DT fuel. The coupling efficiency of laser energy to these fast electrons and the energy deposited in the fuel should be improved [2-5]. From the numerical results, the low-Z cone is expected to be the improvement of coupling efficiency, because the fast electrons are scattered by the large Coulomb potential of highly charged ions in high-Z cone wall [2]. The transport of fast electrons in the cone depends on the electrical conductivity of cone material, especially warm dense matter (WDM).

On the other hand, the fast electron is guided the target by using strong magnetic field, which is order of several teslas, generated by a laser capacitor target [6]. The generated magnetic field using laser capacitor target depends on the coil materials [7,8]. To generate the strong magnetic filed, we should consider the generation rate of fast electrons and the skin effect as an electrical conductivity for ablated plasma at the generation of the magnetic field. To understand its magnetohydrodynamic (MHD) behaviors, we proposed to evaluate the electrical properties using experimental observations and numerical simulation.

In this paper, to survey the optimum materials for fast ignition, we have introduced approaches by using

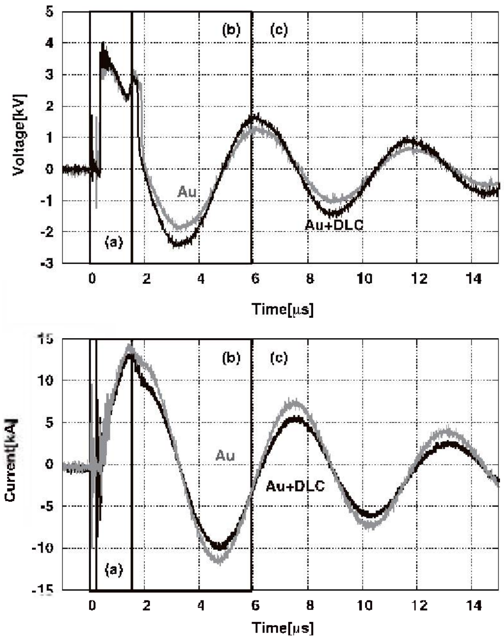


Fig. 1 Typical voltage and current waveforms for Au wire and Au wire +DLC

pulsed-power experiment.

## 2. Exploding Wire Compression for Evaluating Electrical Conductivity in Warm-Dense Diamond-Like-Carbon

The diamond-like-carbon (DLC) [6] cone is promised to increase the coupling efficiency due to the redaction of stopping power in cone compared to the gold cone. However, materials in WDM state are in a complex area where the state is neither solid, conventional fluid nor ideal plasma. We propose a method to investigate the WDM properties of insulator by using pulsed-power discharges[9-14].

From above evaluations, the DLC cone [6], which is one of the low-Z cone, is promised to increase the coupling efficiency due to the redaction of stopping power in cone compared to the high-Z cone. The properties of DLC respects the diamond and the graphite, however, materials in WDM state are in a complex area.

To evaluate the electrical conductivity in DLC WDM, we propose a concept to investigate the WDM properties of insulator by using pulsed-power discharges. The concept of the evaluation of electrical conductivity for DLC WDM is a shock compression

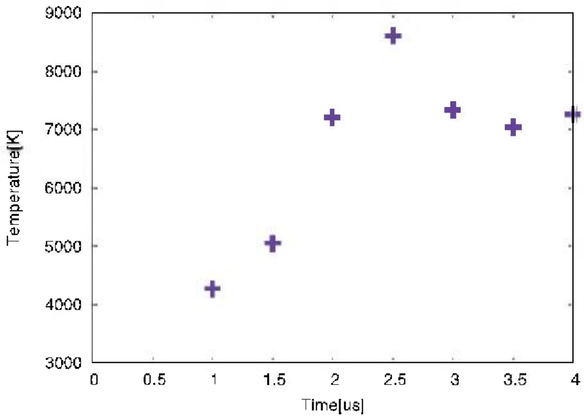


Fig. 2 Time-evolution of DLC temperature

driven by an exploding wire discharge with confined by a rigid capillary [9].

The WDM generation by using pulsed-power discharge is qualitatively evaluation of the electrical conductivity and the other plasma parameters. However, the pulsed-power discharge is difficult to make the WDM for insulator. To evaluate the electrical conductivity for DLC WDM, the shock compression driven by an exploding wire discharge with confined by a rigid capillary is considered. The exploding wire has a huge ablation pressure approximately a few GPa. Thus, the pressure of exploding wire drives the shock heating for the insulator as the DLC membrane, which is coated on the wire. The heated DLC membrane state is observed by the emission spectrum for the temperature. The DLC membrane coated on the wire for gold was fabricated using RF plasma CVD.

Figure 1 shows a time-evolution of voltage and current. As shown in Fig. 1, observed voltage and current waveforms are same at the region (a). The region (a) means that the wire is heated up to vaporization. After the region (a), we can see that the voltage and current waveforms between Au wire and Au wire + DLC is difference because of the difference of the resistance. After the region (c), the capillary was broken by the expansion pressure and the wire/plasma behaves free expansion.

Figure 2 shows a time-evolution of DLC temperature, which is observed by the inversed line-pair method. As shown in Fig. 2, the DLC temperature estimated by the absorption spectrum is up to 9000 K. It means that the warm dense DLC is generated by using proposed method. The electrical conductivity of DLC plasma is roughly estimated to be $10^6$ S/m incorporating hydrodynamic simulation. To determine the correct electrical conductivity of DLC plasma, we should measure the DLC or the wire/plasma size.

## 3.Magntohydrodynamic Behavior of Laser Capacitor Target

The fast electrons are transported with the strong magnetic field, which is order of several teslas, generated by a laser capacitor target [6]. The generated magnetic field using laser capacitor target depends on the coil materials [7,8]. The generated magnetic filed should be considered the generation rate of fast electrons and the skin effect as an electrical conductivity for ablated plasma at the generation of the magnetic field. To understand its MHD behaviors and the electrical properties, we proposed to evaluate experimental observations and numerical simulation [15].

To understand its MHD behaviors and the electrical properties, we proposed to evaluate both experimental observations and numerical simulation. Electrical conductivity for nickel in warm dense matter (WDM) state has been measured with an exploding wire in a quasi-isochoric vessel. To understand the MHD behavior in the laser capacitor target, a two-dimensional MHD simulation has been also demonstrated.

To understand the dependence of generated magnetic field on electrical conductivity distribution in matter, the MHD of single tune coil in the capacitor-coil target with two-dimensional cylindrical geometry has been calculated. The simulation is not incorporated the experimental results. The MHD behavior of capacitor-coil target is solved by conventional MHD equations. The magnetic pressure in the equation of motion was neglected because the kinetic pressure of the plasma was higher than the magnetic pressure.

The wire material, which is determined the equation of state and the transport properties, is aluminum. Coil and wire diameters of the capacitor-coil target at the initial condition were set to be 550 μm and 50 μm, respectively. The electrical conductivity in vacuum region is set to be $10^{-5}$ S/m.

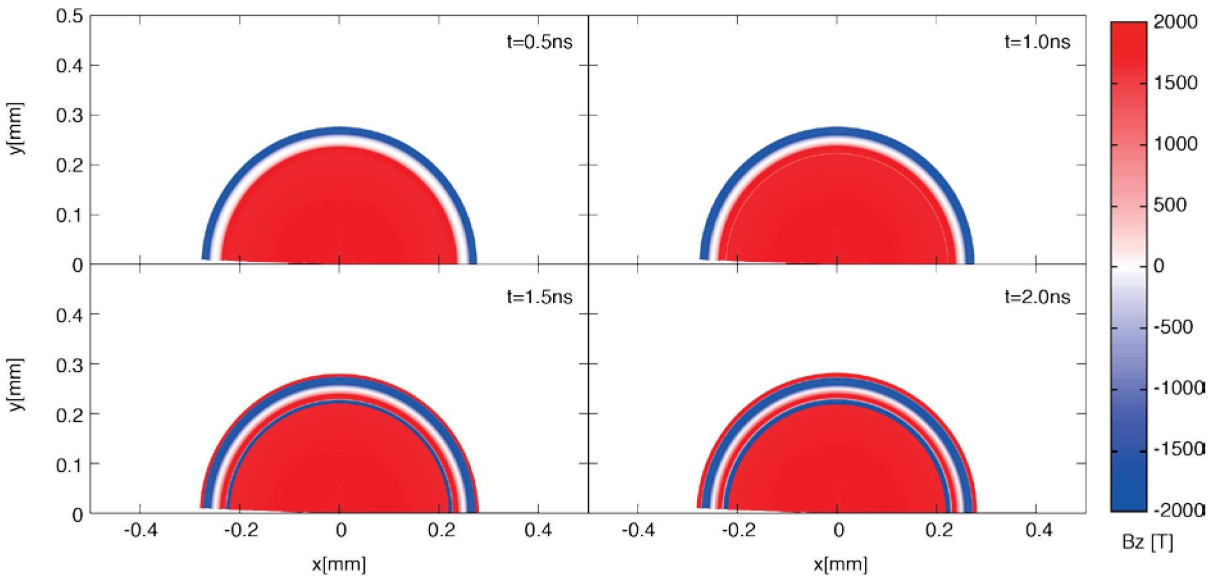


Fig. 3 Time-evolutions of $B_z$-field profile in x-y plane, which is calculated using constant electrical conductivity for the wire.

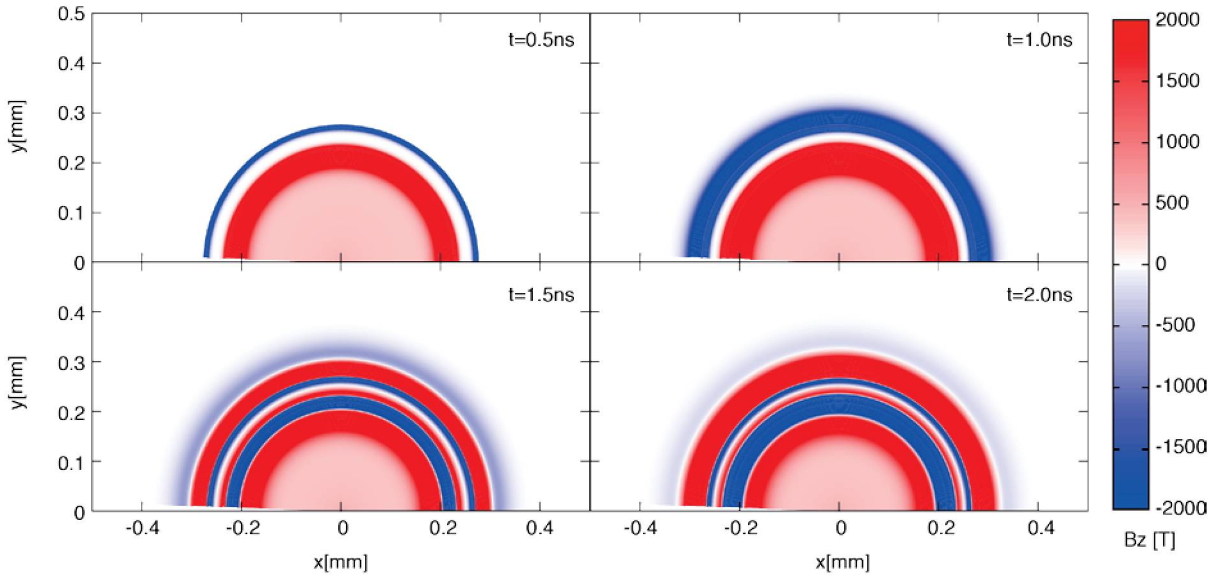


Fig. 4 Time-evolutions of $B_z$-field profile in x-y plane, which is calculated using Lee-More model [16] for the wire.

The capacitor-coil target during the irradiation of intense laser behaves like a current source. The maximum interior magnetic flux density of capacitor-coil coil is approximately 1.5 kT. From the results, to simplify the current evolution $I$(t), we have set sinusoidal wave form with 4 MA of maximum current and 500 MHz of frequency. The displacement current was also neglected since the propagation time of the electromagnetic wave from the inner wire surface to the center of the coil was estimated to be 1 ps. The typical timescale of MHD motion is longer than that of the electromagnetic wave. The timescale in the MHD simulation is ensured.

Figure 3 shows the time-evolutions of $B_z$-field profile, which is calculated using constant electrical conductivity for the wire. The electrical conductivity of wire is set to be $10^5$ S/m. The results shows that $B_z$-field in the coil is almost uniform until $t$=1 ns. After $t$=1 ns, the isolated reversal $B_z$-field is observed. However, the $B_z$-field at the center of coil is positive until $t$=2 ns.

Figure 4 shows the time-evolutions of $B_z$-field profile, which is calculated using Lee-More model [16] for the wire. The results indicated that $B_z$-field in the coil using Lee-More model is rather small compared to that using constant conductivity model. Because the electrical conductivity of wire using Lee-More model is $10^6$ S/m, the B-field diffuses into the coil. However, it is noted that the spatial-temporal distribution of B-field depends on the total current in the coil. Thus, the equivalent circuit model for capacitor-coil target or the total current into the coil will be included the simulation model.

## 4. Conclusions

To survey the optimum materials for fast ignition, we have introduced approaches by using pulsed-power experiment.

To evaluate the electrical conductivity in DLC WDM, we propose a concept to investigate the WDM properties of insulator by using pulsed-power discharges. The concept of the evaluation of electrical conductivity for DLC WDM is a shock compression driven by an exploding wire discharge with confined by a rigid capillary.

To understand the MHD behavior and electrical properties of the laser-capacitor target we have evaluated by experimental observations and numerical simulations. Electrical conductivity for nickel in WDM state has been measured with the exploding wire in the quasi-isochoric vessel. The result shows that the electrical conductivity for nickel in WDM is relatively high from the comparison of the electrical conductivities for several materials in

WDM state. However, the skin effect in the capacitor-coil target will be neglected from the estimation. A two-dimensional MHD simulation for capacitor-coil target has been demonstrated. The results show that the distribution of B-field in the capacitor-coil target depends on the electrical conductivity model.

From above experimental and numerical approaches, WDM properties are important to select material for fast ignition.

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