Development of a Simple Method for Visualization of High-Speed Phenomena

Background

Transient discharges in air occur in a timescale of about 1 microsecond, and clarification of mechanisms of discharge phenomena in air can be expected by visualization of the accompanying density variations. Shadowgraphy [*1], which images the intensity distribution of laser light transmitted through the discharge region, is a simple method to visualize density variations as changes in the brightness of the image. However, conventional CCD cameras are incapable of short exposure times of about 1 microsecond, and ultrafast cameras, which are conventionally used for high-speed photography, are unsuitable for insertion of high intensity light such as laser light. As a new and simple method to obtain the intensity distribution of the laser light at short exposure times, the direction of propagation of laser light can be varied temporarily and inserted into a conventional camera. The use of the acousto-optic effect [*2], which can electronically deflect the laser light without any mechanical movement, is useful for this purpose.

Objectives

To develop a simple visualization method of high-speed phenomena using a laser and the acousto-optic effect, and to apply the method to visualize density variations accompanying transient discharges in air.

Principal Results

1. Visualization of density variations accompanying spark discharges in air

An experimental device to visualize density variations in a region of about 30 cm in diameter was constructed (Fig.1), in which the laser light was expanded by a reflective astronomical telescope. Using this device, density variations accompanying a spark discharge in air were visualized (Fig.2). Since the spark discharge is accompanied by very strong optical emission, such visualization was not possible by conventional methods using flash sources such as strobes. In this research, the effect of the optical emission from the discharge was successively removed by using a laser light source and making use of its monochromatic and directional properties.

2. Visualization of density variations accompanying pre-breakdown phenomena

Prior to the occurrence of a spark discharge in air (insulation breakdown), a leader (region in the form of a bent line with low ionization, which leads to the main discharge) progresses mainly from the high voltage side to the grounded side. Here, the density variation accompanying a leader was visualized (Fig.3). When no breakdown occurs, streamers (regions in the form of bent lines with lower ionization than leaders) progress from the high voltage side in numerous paths, whose accompanying density variations were also successfully visualized. In the past, observation of pre-breakdown phenomena such as leaders and streamers consisted mainly of imaging the optical emission, but the patterns of density variation and of optical emission do not necessarily coincide. The method developed in this research enables direct observation of density variations, a fundamental physical quantity, which can be used for clarification of discharge mechanisms.

Future Developments

Application of this method to fields of research other than discharges will be considered.

Main Researcher: Tetsuo Fukuchi, Ph.D.,
Research Scientist, Applied High Energy Physics Sector, Electric Power Engineering Research Laboratory

References

T. Fukuchi, et al., 2005, “Visualization of high-speed phenomena using an acousto-optic laser deflector”, IEEJ Transactions on Fundamentals and Materials, Vol. 125, No. 2, pp. 113-118 (in Japanese)

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*1 : *Shadowgraphy*: a method to visualize the density variations along the light path, based on the refraction of light by the density variations. The regions of large density variations appear dark.

*2 : *Acousto-optic effect*: phenomena in which the properties of light change owing to the interaction with acoustic waves. Here, an acousto-optic deflector, which alters the direction of propagation of laser light by acoustic waves in a crystal, was used. The acoustic waves are excited by applying high frequency signals to a transducer connected to the crystal.

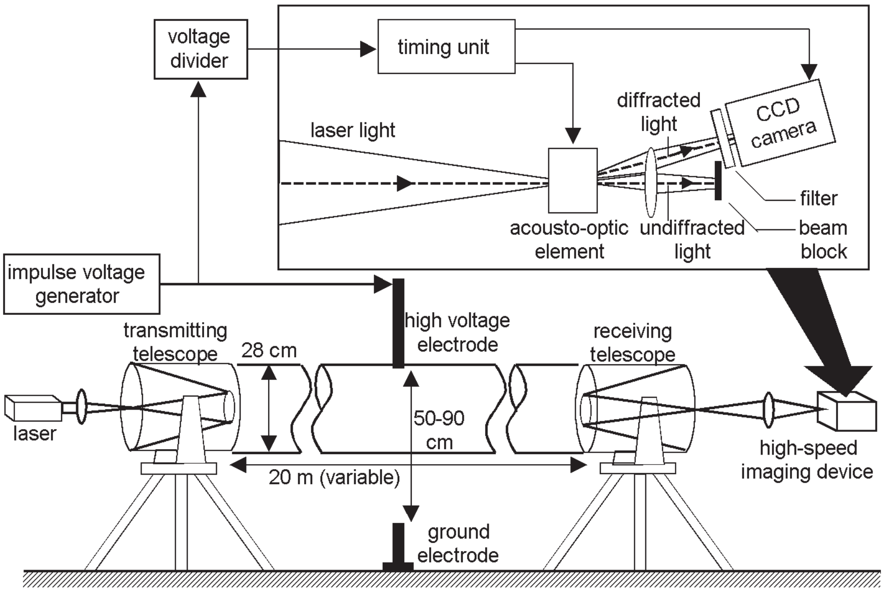

Fig.1 Schematic diagram of the device for visualization of density variations in air, and conceptual diagram of high-speed imaging (insert)

Laser light is expanded by the transmitting telescope, passed through the discharge region, reduced by the receiving telescope, and directed into the acousto-optic element. The diffracted light is generated only during a time period of several microseconds, in synchronization with the discharge. Using this setup, the intensity distribution of laser light can be imaged with exposure times of several microseconds.

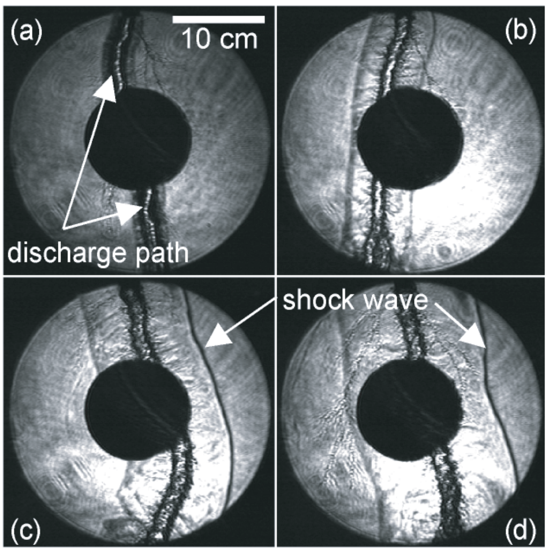

Fig.2 Visualization of density variations accompanying an impulse spark discharge in air

The dark portions of the image indicate the regions of large density variation. The dark circle at the center is the shadow of the secondary mirror of the telescope used to expand the laser light. Images (a)-(d) were obtained with the exposure set to begin 8, 58, 108, 158 microseconds relative to the spark discharge.

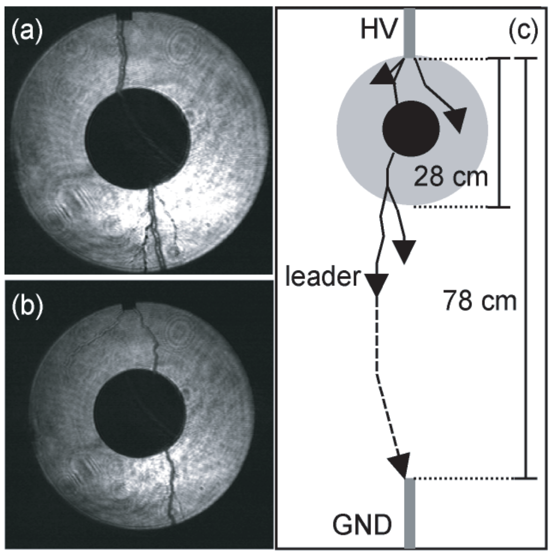

Fig.3 Visualization of density variations accompanying the progression of a leader

The dark portions of the image indicate the regions of large density variation accompanying the progression of a leader. Images (a), (b) were obtained before the occurrence of the spark discharge; (c) is a schematic diagram indicating the discharge gap, measurement region, and leader progression.