Recently, compact high intensity discharge lamps (HID lamps) have attracted increasing interest in light sources for data projectors or the headlamps for the motor cars because of their strong light emission, long life time and small plasma volume for light radiation. Most compact HID lamps are conventionally operated by AC discharge. According to our previous work [1], it is verified that D2 type metal halide lamps for motor cars application can be discharged stably by 2.45 GHz microwave from solid state microwave generators (CHRONIX : HPA100), showing luminous efficacy higher than that operated by AC discharges. It is considered that the electrodes in the D2 type lamps can work as the monopole antenna and that the microwave power can be directly fed into the electrode gap of 3.5 mm without heating the envelope glass and electrode wires of the lamp, which results in improvement of the luminous efficacy. To distinguish the present microwave discharge from the conventional AC and microwave discharges, antenna-excited microwave discharge (AEMD) is hereafter assigned to emphasize the role of the monopole antenna for microwave power supply into the lamp. In the present work, the lamp properties ignited by pulse–modulated microwave were investigated to aim to improve luminous efficacy furthermore.

Commercially available D2 type metal halide discharge lamps in which xenon of 5 atm and small amount of chemical additives (Hg : 0.5 mg and NaI+ScI₃ : 0.5mg) are filled have been used in the present work. It is reported that the luminous efficacy of the lamp is around 100 lm/W when it is operated by AC electric power of 35 W. The total length of the tungsten electrodes of a 0.25 mm diameter including the gap length of 3.5 mm is 30 mm, which corresponds to 1/4 microwave wave length so that the D2 type lamp can be used as AEMD metal halide lamp. The gas pressure in the lamp becomes higher than 10 atmospheres during the lamp ignition.

At first, the luminous efficacy \( \eta \) and total luminous flux \( F \) were measured as a function of continuous microwave power, where \( F \) was obtained from an illuminance \( E \) measured by the luminance meter (Minolta:T1-M) at \( R = 0.5 \) m from the lamp center using the relations of \( F = 4\pi R^2 E \) and \( \eta = F/W_m \). The microwave power into the lamp \( W_m \) is calculated by considering the reflected microwave power to the solid state microwave generator and the loss factor of the coaxial cable. Figure 1 shows \( F \) and \( \eta \) measured as a function of \( W_m \) together with \( \eta \) for D2 lamp ignited by AC electric power. It is found that \( F \) increases linearly with microwave power\( W_m \), while \( \eta \) reaches a saturated value of 135 lm/W, which is higher than 110 lm/W for the D2 lamp operated by AC electric power at 35 W, measured by the same method used in the case of AEMD D2 lamp.

Next, the pulse modulated microwave power is used to sustain the AEMD D2 lamp. Figure 2 shows one of the relations between \( \eta \) and time-averaged microwave power of microwave pulse at the duty ratio of 66.7 % as a function of the pulse frequency. It is found that measured \( \eta \) for
the microwave pulse ignition becomes as high as 195 lm/W at the pulse frequency of 30 kHz.
To clarify the reason of the increase in $\eta$, the temporal change of visible light intensity from
the lamp was measured by PIN photo-diode (HAMAMATSU Photonics: Type S5972) as a
function of the pulse duty ratio, where the pulse height is kept constant at 70 W. It is seen in
Fig.3 that the fluctuation of the visible light decreases with increase in pulse frequency and that
the decay time of the visible light is longer than 100 $\mu$s. It is considered that the long decay
time of the visible light from AEMD D2 lamp sustained by the pulse modulated microwave is
due to ionization of metal halide materials by high energy plasma in the antenna gap continuing
even in a pulse off duration because of their low ionization potential, which leads to higher $\eta$.

The structures of the plasma column generated in the antenna gap were taken in the picture.
There are straight (spindle type) and curved plasma columns. With increasing the incident
microwave pulse height, the plasma column sometimes changed to the curved one, which is
caused by high density plasma which reflects the microwave power on the surface of the plasma
column. However, $\eta$ is not so sensitive to the plasma column structure though once a part of
the curved plasma column touches the lamp wall, the lamp wall temperature becomes lower
than 900 °C and $\eta$ decreases.

Fig.1 Luminous efficacy $\eta$ and luminous flux $F$ v.s microwave power $W_{in}$
Fig.2 Luminous efficacy $\eta$ versus time-averaged microwave power $W_{in}$ as a function of
microwave pulse frequency.

Fig.3 Temporal change of visible light from
AEMD D2 lamp ignited by pulse modulated
microwave. Duty : 67 %. Microwave pulse
height is kept constant

Reference
[1] M. Kando, T. Fukaya and Y. Ohishi 11th Int’l Symp. on the Science and Technology of Light Sources,
(May 2007, Shanghai) 313