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Measurement of the Semiconductor Bridge (SCB) Plasma Temperature by the Double Line of Atomic Emission Spectroscopy

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Abstract: A system consisting of two interference filters of different wavelength and two photo-multiplier detectors was used to measure the time evolution of the SCB plasma temperature based on the double line of atomic emission spectroscopy. The highest temporal resolution of the apparatus was 0.1 μs. The results show that when the voltage is 24 – 32 V and all capacitances are 68 μF, the highest temperature and duration of the SCB plasma increases from 2710 K to 3880 K and from 170.7 μs to 283.4 μs, respectively.

Key words: applied chemistry; SCB plasma; emission spectroscopy; temperature measurement

CLC number: TJ55; O657.31　　**Document code**: A

1　Introduction

The semiconductor bridge (SCB) initiator, a small semiconductor device[1-4] that generates plasma for the ignition of explosives represents a novel kind of initiating device. It has developed very rapidly due to its excellent properties, such as high safety, low energy[5,6] and readiness of incorporation with digital logic circuits. The information of the SCB plasma is important to understand the SCB initiator efficiency and the energy transfer mechanism. Previously Jongdea Kim[7-9] et al., used the microwave resonator probe to measure the SCB plasma density. But few documents about the accurate measurement of the SCB plasma temperature was found.

Because the duration of SCB plasma is hundreds of microseconds and the diameter is less than 1 cm, almost all common diagnoses of the plasma, such as laser Thomson Scattering, Langmuir probe etc., are inefficient.

With the information observed and utilized from the SCB plasma emission spectroscopy, some[1,10] estimated the temperature, identified emission species or studied the generation mechanism of the SCB plasma. However the methods of Benson[1] and Jongdea Kim[10] were not economical and the SCB plasma temperature they estimated were not accurate.

A system based on the double line of atomic emission provided a simpler and more economical method to obtain the SCB plasma temperature. The system had already been successfully used by Junde Wang et al. to measure the discharge spark temperature of nonel igniter[11] and the gas temperature in the chamber of solid rocket motor[12]. It was used to discuss the time evolution of the SCB plasma temperature in this paper.

2　Experimental

2.1　Theory of the measurement system

The double line of atomic emission spectroscopy method, i.e. the plot of Boltzmann function, is a better and simpler method for measuring the SCB plasma temperature. The relationship between the SCB plasma temperature and relative intensity of the double line of the same atomic is given as follows[13,14]:

$$\ln\left(\frac{I_{\lambda_1}}{I_{\lambda_2}}\right) = \ln\left(\frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\right) - \frac{E_1 - E_2}{kT} \quad (1)$$

then

$$T = \frac{1}{k}\frac{E_2 - E_1}{\ln\left(\frac{I_{\lambda_1}}{I_{\lambda_2}}\right) - \ln\left(\frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\right)} \quad (2)$$

where λ is spectral wavelength, I is line relative intensity, g is statistical weight of upper level, A is transition probability, E is energy of the upper level, k is Boltzmann's constant, T is temperature of the plasma.

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For the two given spectral lines, $A_1, A_2, g_1, g_2, \lambda_1, \lambda_2, E_1, E_2$ and k are all constants. When the relative intensities, I_{λ_1} and I_{λ_2}, are obtained, the SCB plasma temperature can be derived from Equation (2). The effect of the spectral radiance and spectral transmissivity on the spectral measurement decreases, especially when the interval of two spectral lines is very small. In this paper, the two spectral lines were Cu Ⅰ 510.5 and Cu Ⅰ 521.8 nm.

The measurement system consisted of two different wavelength interference filter, two photo-multiplier detectors (R300), a fast responding circuit, a data-acquisition card and a 486 PC. The diagram of measurement system is shown as Fig. 1.

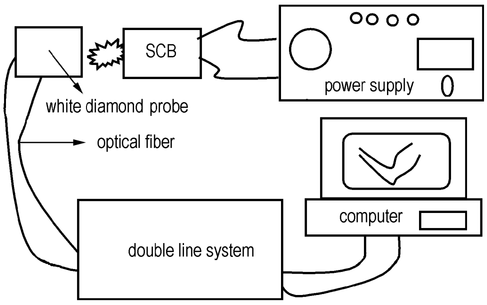

Fig. 1 The diagram of measurement system

2.2 The SCB

The SCB heavily n-type dopant concentration is about 1×10^{20} phosphorus atoms/cm^3. The size is 100 μm long by 400 μm wide by 2 - 3 μm thick. Its resistance about 1 Ω is designed for considering the electrostatic safety. Its typical structure is an "H"-shaped thin poly-silicon-on-silicon film with two Al lands for electrical contacts, as shown in Fig. 2.

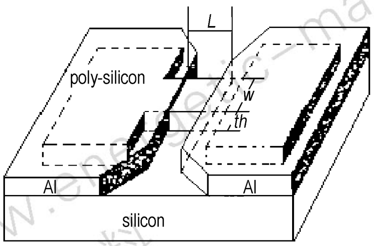

Fig. 2 The diagram of SCB structure

The apparatus is mounted on a solid insulator (ceramic), which insulates the SCB from the main housing of the ignition unit. It should be noticed that the SCB materials contains a few copper, which is critical for this measurement method. And it is different in volume and dopant concentration from the one Benson[1] and Jongdea Kim[10] adopted.

2.3 Experimental process

A firing set selected in the experiment consisted of a capacitor (68 μF) and a power supply. With it, the bridge materials were heated by electricity. The bridge melted down firstly, and then vaporized. Once the bridge materials were vaporized completely, the current flowed through the vapor, producing the plasma discharge called the late-time discharge (LTD). In this test the SCB discharged to room air directly and a white light was observed with an audible "pop". The relative intensity of the double line of Cu-atomic emission (I_{λ_1}, I_{λ_2}) from the SCB plasma was detected by photo-multiplier, through which the optical signal was transformed to electrical signal. Then the obtained signals were stored in computer for further analysis.

3 Results and discussions

The experimental results obtained under the conditions are given in Table 1.

Table 1 Experimental conditions and results

group	power supply/V	capacitor/μF	plasma life time/μs	temperature/K
1	24	68	170.7	1790 - 2710
2	25	68	198.9	1730 - 3260
3	27	68	207.3	1790 - 3390
4	30	68	211.4	1750 - 3480
5	32	68	283.4	1770 - 3880

The processing of the third group of data is taken as an example to describe how the results were obtained. The experiment was carried out under the condition of a given power supply (30 V) and capacitance (68 μF). Fig. 3 shows the signal obtained from the double line of the system.

Because the measurement system recorded the SCB plasma light, the signal could be treated as the onset of the late-time discharge (LTD). The curve in Fig. 4 shows the time evolution of the SCB plasma temperature, which illustrate that the SCB plasma temperature increases from 1750 K to 3480 K during the period of 211.4 μs.

Other data were processed in the same way. It can be concluded that the highest SCB plasma temperature increases with the rise of the input energy. And the same tendency can be seen in the duration of the SCB plasma. The SCB plasma temperature in every test at the onset of the late-time discharge (LTD) was similar, being 1750 K approximately. The main component of the SCB was silicon. The SCB size was about $2\ \mu m \times 100\ \mu m \times 400\ \mu m$, and Si-atoms was approximately 4×10^{15}. The SCB was doped with a concentration of about 1×10^{20} phosphorus atoms/cm^3, so there were about 8×10^{12} phosphorus atoms in SCB. Due to the influence of phosphorus atoms, the vaporization temperature of the SCB was lower than that of pure silicon (2628 K).

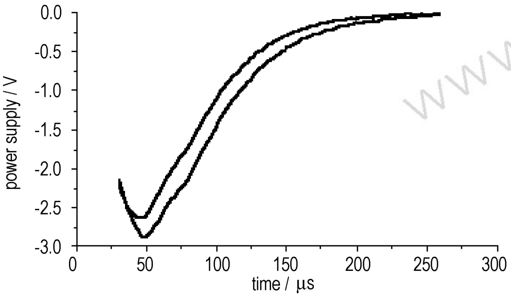

Fig. 3 Time evolution of relative intensities (I) of two copper lines

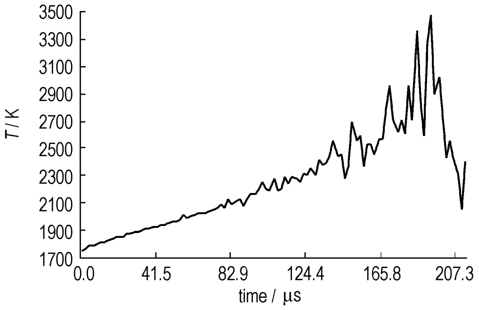

Fig. 4 Time evolution of the SCB plasma temperature

4 Conclusions

The temporal resolution of the system is 0.1 μs, which is suitable for measuring instant SCB plasma temperature. Moreover, the time evolution of the SCB plasma temperature can be obtained from this system. The SCB discharge was comprehended more economically and easily. The following conclusions can be drawn: (1) The onset of the late time discharge (LTD) of the SCB plasma temperature is about 1750 K, which has little relationship with the input energy. (2) In each late-time discharge (LTD) of the SCB, the temperature increases with the time evolving. (3) The highest temperature and duration of the SCB plasma are closed related to the input energy. They increase with the increasing of the input energy.

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Effects of the Binding Agents on the Burning Rate of the Tungsten Delay Composition

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Abstract: To study the effects of the binding agents on the burning rate of the tungsten delay composition, two delay compositions in bound form were made with nitrocellulose and Teflon separately. An experiment on the two delay compositions was carried out and their delay time at room temperature and high temperatures(120, 160, 180 ℃) were obtained. The results show that the burning rate of the composition with nitrocellulose as binding agent is much faster than that of the composition with Teflon as binding agent. When the temperature rises, the burning rate of the composition with nitrocellulose as binding agent increase rapidly while the burning rate of the composition with Teflon as binding agent does slowly.

Key words: applied chemistry; delay composition; tungsten type delay composition; binding agent; burning rate

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原子发射光谱双谱线法测量半导体桥(SCB)等离子体温度

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摘要：在原子发射光谱双谱线法的基础上，设计了含有两个干涉滤光片和光电倍增管双谱线测温系统。仪器的最高的时间分辨率为 0.1 μs。讨论了不同能量输入条件下 SCB 等离子体的温度和等离子体的存在时间。实验结果表明在电压 24 ~ 32 V，电容 68 μF 不变的情况下，等离子体的温度从 2710 K 升高到 3880 K，等离子体存在时间从 170.7 μs 上升到 283.4 μs。

关键词：应用化学；SCB 等离子体；原子发射光谱法；温度测定

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Safety Fault Analysis of Igniter Based on FTA and BN

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Abstract: Bayesian networks(BN) and fault tree analysis(FTA) were compared for safety fault analysis. According to the initiator system, a new method that used FTA & BN to perform fault analysis was proposed. The reasons causing safety fault to the igniter with the method were analysized as the non-uniform density of delay powder, the sticking of protechnic charge to the internal wall of delay tube and the failure of alarm device, etc. The corresponding solution was established at end.

Key words: safety engineering; initiators; igniter; fault analysis; bayesian networks (BN); fault tree analysis(FTA)