Electrode Performance of Oxide-Containing Tungsten Materials in Direct Current Arcs

直流アークにおける酸化物入りタングステン電極の性能

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Abstract

We developed cerium-oxide-containing tungsten (CeO_2-W) as an alternative for thorium-oxide-containing tungsten (ThO_2-W) used as cathode of plasma torches. We evaluated the performance of neodymium-oxide-containing tungsten (Nd_2O_3-W), lanthanum-oxide-containing tungsten (La_2O_3-W) and CeO_2-W as cathode electrodes for DC arcs under a nitrogen atmosphere and analyzed the consumption mechanism. Under a nitrogen atmosphere, CeO_2-W showed lower erosion than ThO_2-W. This is because the surface temperature of cathode of CeO_2-W was lower than that of ThO_2-W. On the other hand, the erosion rate using Nd_2O_3-W and La_2O_3-W as the cathode was higher than that using ThO_2-W, unlike the results under argon atmosphere reported previously [1]. We inferred that this is caused by the decomposition of these oxides (Nd_2O_3, La_2O_3) by nitrogen radicals.

We compared the erosion rate using CeO_2-W as a cathode under an argon atmosphere with the erosion rate of the cathode (Pure-W, Nd_2O_3-W, ThO_2-W, La_2O_3-W) under an argon atmosphere in a previous report [1]. The erosion rate using CeO_2-W as the cathode was also the lowest under an argon atmosphere.

The factors that cause consumption of electrodes are different in argon and nitrogen atmospheres. Among the tungsten materials currently used industrially, CeO_2-W is the most effective material in terms of erosion resistance under both atmospheres.

プラズマトーチなどの陰極として使用されている，ThO_2-W の代替材として，CeO_2-W，Nd_2O_3-W，および La_2O_3-W を直流アーク用の陰極電極として使用し，窒素雰囲気下における性能評価及び，消耗のメカニズム解析を行った．窒素雰囲気下にて，CeO_2-W は ThO_2-W よりも低い消耗量を示した．CeO_2-W は ThO_2-W より陰極電極の表面温度が低下しており，この効果により電極消耗量が減少したと推察される．

一方，Nd_2O_3-W と La_2O_3-W は前回報告[1]したアルゴン雰囲気下の結果とは異なり，ThO_2-W と比較して消耗量が増加した．これは窒素ラジカルによる酸化物（Nd_2O_3、La_2O_3-W）の分解が起因していると推察される．

さらに，アルゴン雰囲気下における CeO_2-W の陰極電極の消耗量についても同様の測定を行い，前回報告[1]したアルゴン雰囲気下におけるその他の陰極電極 (Pure-W, Nd_2O_3-W, ThO_2-W, La_2O_3-W) の消耗量と比較した．その結果，CeO_2-W の消耗量は最も低くなった．

使用する雰囲気下によって電極消耗要因が異なるため，現在工業的に使用されているタングステン材料の中で，どちらの雰囲気下においても耐消耗性に有効な材料は，Ce_2O_3-W と考えられる．

1. Introduction

In industrial fields, coating technologies such as plasma spraying are used to reduce damage and loss of functionality of components. ThO_2-W was generally used for the cathode electrode in plasma spraying. Since ThO_2-W contains radioactive material (thorium), it was necessary to switch to a non-radioactive material. Furthermore, a material with lower erosion rate than ThO_2-W was required [2].

In this study, CeO_2-W was developed as alternatives to ThO_2-W for the cathode of the direct current (DC) arc of plasma torches.

2. Experimental

A schematic of the DC arc generator in Watanabe laboratory of Kyushu University used in the experiments is shown in **Fig. 1**. Five types of cathode materials were used: Pure tungsten (Pure-W), Nd_2O_3-W, CeO_2-W, ThO_2-W and La_2O_3-W. All cathode electrodes had a diameter of 6 mm with a tip angle of 60°. Molybdenum was used for the anode.

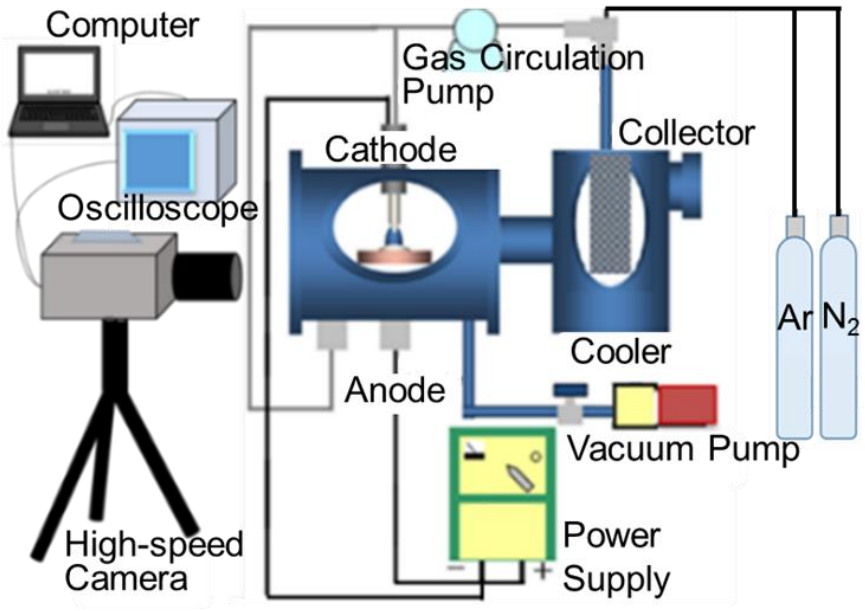

Fig. 1 Schematic of the DC arc generator

These experiments were performed under an argon-nitrogen 50% atmosphere or an argon 100% atmosphere. An arc was generated between the cathode and the anode by applying an arc current of 100 A. The distance between the electrodes was 10 mm and the flow rate of the shielding gas was 10 L/mm. The cathode surface temperature was measured using BPFs at wavelengths of 785 ± 2.5 nm and 880 ± 5.0 nm. This system using BPFs enables cathode radiation measurements without interference from other emissions in the plasma. The cathode surface temperature was estimated based on the two-color pyrometry, as shown in **Fig. 2**.

The tungsten erosion rate was estimated by measuring the cathode weight before and after the experiment.

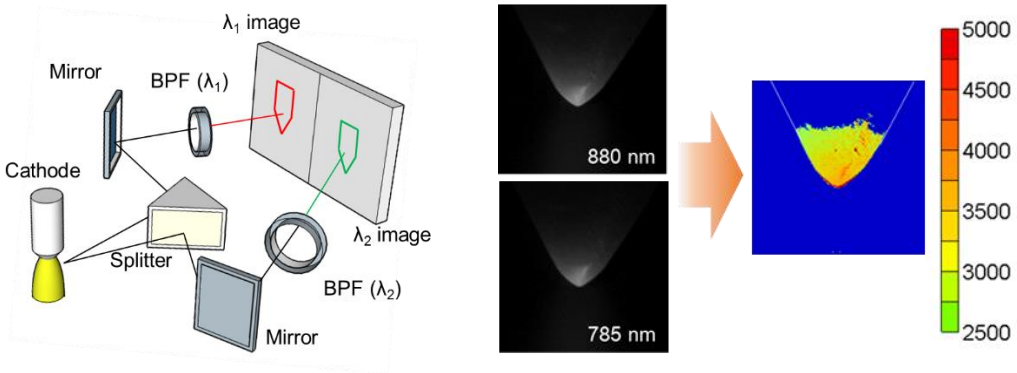

Fig. 2 Conceptual diagram of the cathode temperature measurement by a high-speed camera using BPFs.

3. Results and Discussion

The erosion rates of the five cathode materials (Pure-W, ThO_2-W, Nd_2O_3-W, CeO_2-W, La_2O_3-W) in an argon-nitrogen 50% atmosphere are shown in **Fig. 3**. The erosion rate using CeO_2-W was lower than that using ThO_2-W. This is due to the difference in electrode surface temperature shown in **Fig.4**. As shown in **Table 1**, the melting point of CeO_2 is lower than that of ThO_2, so the area of molten Ce oxide covering the cathode surface is large. It is thought that as the area where plasma was generated increases, the current density decreased and thus the electrode surface temperature decreased.

On the other hand, the erosion rate using Nd_2O_3-W and La_2O_3-W as the cathode was higher than that using ThO_2-W. The erosion rate of the La_2O_3-W electrode could not be measured because its plasma was unstable, and the electrode was considerably eroded. This result was different from the erosion rate under an argon atmosphere reported in the previous report [1]. It is inferred that this is caused by the decomposition of oxides (Nd_2O_3, La_2O_3) by nitrogen radicals. In the future, it is necessary to confirm the decomposition reaction of oxides by nitrogen radicals.

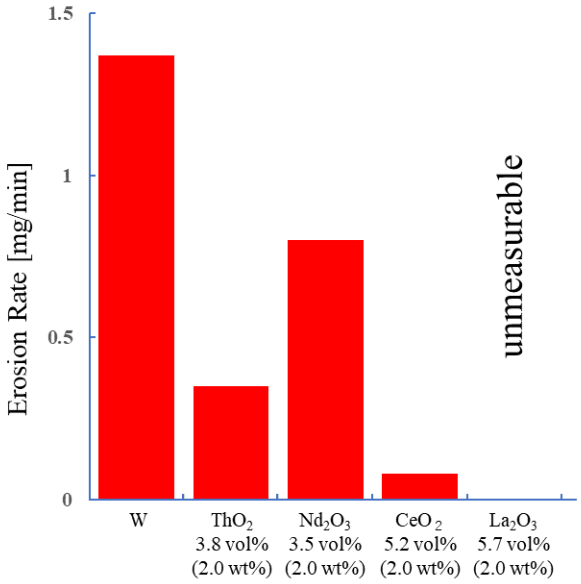

Fig. 3 Comparison of the erosion rates of the five cathode materials under an argon-nitrogen 50% atmosphere

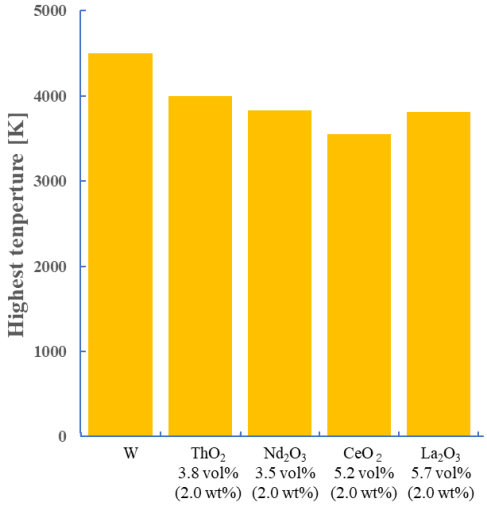

Fig. 4 Comparison of surface temperature of electrode under an argon-nitrogen 50% atmosphere

Table 1 Work functions and melting points of the cathode materials

Emitter	Work Function (eV)	Melting Point (K)
W	4.5	3,695
ThO_2	2.7	3,323
Nd_2O_3	2.3-3.3	2,506
La_2O_3	3.1	2,490
CeO_2	3.2	2,870

Furthermore, we conducted the erosion test under an argon 100% atmosphere five cathode materials. We compared the present results with the erosion rates of other materials under an argon 100% atmosphere reported in the previous report [1]. The results are shown in **Fig. 5 (a)**. **Fig. 5 (b)** shows an enlarged view of the area other than the Pure-W data. The erosion rate using CeO_2-W as the cathode was lowest under an argon 100% atmosphere.

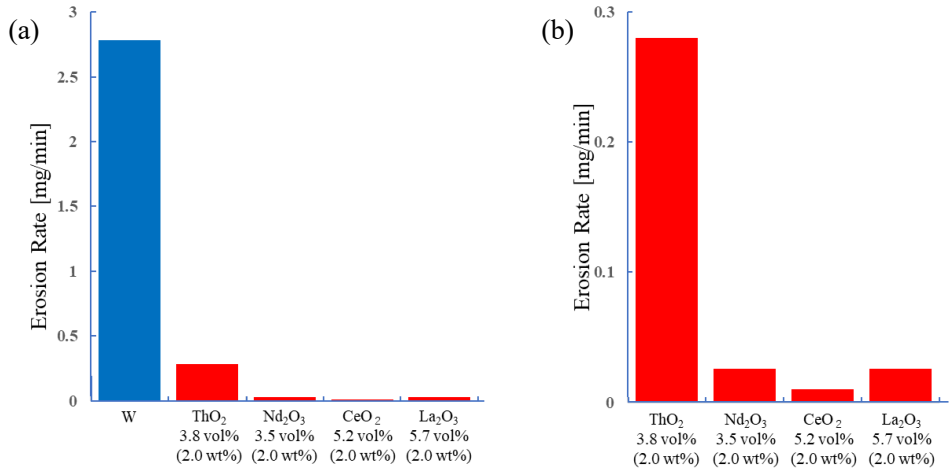

Fig. 5 Comparison of the erosion rates of the five cathode materials under an argon 100% atmosphere

4. Conclusion

Under a nitrogen atmosphere, only the DC arc cathodes of CeO_2-W showed lower erosion rates than that of the ThO_2-W. CeO_2-W had the lowest erosion rate even under an argon atmosphere.

The erosion rates of the oxide-containing tungsten (Nd_2O_3-W, La_2O_3-W) cathodes were different in an argon atmosphere and a nitrogen atmosphere. CeO_2-W is the most effective material for the DC arc material in both atmospheres.

References

[1] S.Shimizu, T.Mouri, K.Fujii, A.Mishma, T.Watanabe Nippon Tungsten Review Vol 41 2017

[2] M. Heißl, C. Mitterer, T. Granzer, J. Schröder, M. Kathrein, *18th Plansee Seminar*,Austria, 2013.