Application of Metal (Carbide)-Carbon Eutectic Fixed Points in Radiometry

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Abstract. Application of metal (carbide)-carbon eutectic fixed points to radiometry has its own specific requirements: temperature preferably exceeding 3000 K, large aperture, robustness, and long plateau duration. The large aperture BB3500YY furnace, newly introduced at the NMIJ, has been optimally tuned for fixed point realization. Together with a novel cell structure that utilizes an inner insulation by carbon composite sheet material, the requirements are close to becoming reality.

Introduction

Radiometry and radiation thermometry have large technical similarities. The emergence of the high-temperature metal-carbon (M-C) and metal carbide-carbon (MC-C) eutectic fixed points in radiation thermometry will inevitably have a major impact on radiometry [1]. In this paper, possible application of the fixed points to radiometry will be outlined, and requirements specific to these applications will be spelled out. At the NMIJ, efforts to meet these requirements have been initiated and, although still preliminary, promising and highly important improvements are already achieved. This paper attempts to capture and report these most recent developments.

The impact on radiometry

The Metal (Carbide)-Carbon eutectic fixed points can potentially be utilized in many aspects of radiometry. For instance, simply taking advantage of its repeatability and long-term stability, one can monitor the stability of filter radiometers easily and accurately over an extended period of time.

The fixed points, with the knowledge of its thermodynamic temperature, can serve to reduce two major sources of uncertainty in the realization of the primary spectral irradiance scale: the blackbody source temperature and the effective emissivity of its cavity (due to temperature gradient along the cavity wall). Either by transferring the fixed-point temperature of a given eutectic to a large-aperture blackbody by means of a radiation thermometer, or by directly calibrating FEL lamps against a large-aperture fixed-point blackbody source, the first of the two is achieved. The large aperture fixed-point irradiance source inherently achieves cavity temperature uniformity and thus overcomes the second.

The use of the fixed points enables spectral radiance and irradiance calibration obviating the need for a full detector-based calibration facility and as frequently as necessary. The TiC-C point is very promising in this respect since the colour temperature is almost the same as that of the FEL 1 kW lamps. The high-temperature sources exceeding 3000 K have the potential of a highly reproducible UV source. For instance, UV networks that observe the change in ozone layer thickness by linking UV solar monitors worldwide can benefit from a direct calibration of the instruments against these sources in the UV B range.

Requirements specific to radiometry

The radiometric applications impose requirements to the fixed points that are not always met in their applications to thermometry.

1) The temperature needs to be high, so the fixed points of interest are those beyond the Re-C point (2747 K), especially the MC-C points (δ(Mo carbide)-C: 2856 K, TiC-C: 3034 K, ZrC-C: 3156 K, HfC-C: 3458 K). The MC-C fixed points, although there is no indication of inferior performance, have not yet been fully investigated. Thus far, the MC-C points have only been constructed and tested at the NMIJ and the VNIIOFI. A comparison for the TiC-C point has been made between these institutes, and an agreement of 0.24 K, or 0.06 % in terms of the spectral radiance at 650 nm, has been observed [2]. The high temperature entails two complications: the limitation in the operating temperature of the furnaces commonly available, and the breakage of cells due to the large temperature change they experience.

2) To be an irradiance source the cell needs to have an aperture larger than 8 mm in diameter and possibly larger than 10 mm.

3) To use the cells for spectral calibrations, the plateau duration should cope with the time needed for the monochromator to scan the wavelength over the required wavelength range.

Recent developments at the NMIJ

In view of the above requirements imposed by the radiometric applications, two major developments have been pursued recently at the NMIJ.

1) The introduction of a large aperture BB3500 furnace

A new BB3500YY furnace (manufacturer: VEGA International) with a large furnace-tube inner diameter of 47 mm has been designed at the VNIIOFI and installed at the NMIJ, which can reach 3500 K. Work has been performed to push the furnace to its maximum capability. Temperature distribution measurements have been performed and the temperature uniformity has been optimised. The furnace, which uses a stack of pyrolitic graphite rings as the heater / furnace tube, has the feature that the axial temperature distribution can be optimized by selecting the optimum order of the ring elements in the furnace after having measured the electrical resistance of each of them before at room temperature. The furnace-temperature uniformity after optimisation, measured with a radiation thermometer, was within 2 K over 40 mm, roughly corresponding to the length of the fixed point cell (45 mm). Details are presented in another presentation at this conference [3].

2) Inner insulated fixed-point cell

The other improvement is the use of purified carbon cloth material (C/C sheet TCC-019, manufacturer: Toyo Tanso Co. Ltd., impurity content: less than 10 ppm) inside the graphite crucible. The CC composite sheet has thickness of 0.5 mm, and up to 4 layers were inserted between the metal and the graphite crucible wall. This cell structure has several advantages:

(1) The C/C sheet acts as a physical buffer layer that keeps the outer wall of the crucible free from any stress, thus preventing breakage. This method has been successfully applied to Re-C point cells and no breakage has occurred since.

(2) The cell becomes relatively immune to temperature nonuniformity of the furnace. The sheet acts as a thermal insulator in the direction perpendicular to the sheet. The sheet is strongly anisotropic and good thermal conductance is achieved in the lateral direction along the surface, thus enhancing temperature uniformity in the ingot.

(3) The plateau duration is extended, due to the thermal insulation of the sheet.

(4) The amount of the metal required to fill the cell is reduced, while still maintaining the same plateau duration and shape.

(5) The time required for filling a cell is drastically reduced. The filling process is basically an iterative process, and thus usually the final "topping off" with metal powder takes time. However, since the cell no longer needs to be filled completely, and the remaining gap can be filled by C/C sheet layers, it can be filled in approximately half of the time needed thusfar. The last two points are quite effective in reducing the price of these fixed-point cells.

Applicability of this technique to MC-C eutectics is currently under investigation. The technique also paves the way for realizing large aperture cells required for irradiance sources. The solution to the breakage problem enables accommodation of the large-aperture cavity in a cell with the same outer diameter by reducing the outer-wall thickness. The extended length of the cell is expected not to be a problem because of the enhanced immunity to furnace-temperature nonuniformity. Preliminary results will be presented.

The inner insulated cell relaxes the requirement on the furnace temperature uniformity. However, if the cell is combined with a furnace with good temperature uniformity, the plateau quality is further improved. An example is shown in Fig. 1, where a Re-C cell with 3 mm cavity aperture and with a single layer of C/C sheet inserted between the 74 g of the eutectic metal and the outer crucible wall was placed in the BB3500YY furnace. A plateau extending well over 30 minutes was obtained, which is three times longer than what is usually observed with a cell with the same outer dimension.

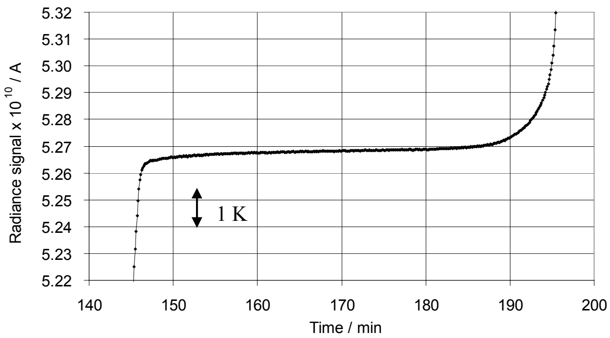

Figure 1. Melting plateau of a Re-C fixed point cell with a single layer of C/C sheet. Furnace: BB3500YY.

Conclusion

The eutectic fixed points hold promise for becoming indispensable tools for radiometry in the near future. Major obstacles for their successful applications are now being cleared away. Involvement of radiometrists in the development of M(C)-C eutectics is strongly encouraged, allowing thermometrists to profit from their expertise. From the thermometric point of view the fixed-point temperatures need to be determined with the smallest uncertainty possible, and thus thermodynamic temperature measurements based upon radiometric methods are deemed to be essential.

References

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