Surface modification of graphite and ceramics with metals using induction heating

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Abstract. In order to join metals to graphite or ceramics by soldering or brazing, a new surface modification method using induction heating was developed for graphite and ceramics. Such source metals as Cu, Ni, Cr, etc. were induction-heated in vacuum atmosphere and making deposited films on the deposition substrate, or the target substrate; graphite, AlN, Si₃N₄. The applicability of this method was investigated and the deposited layer was analysed by SEM observation, Auger electron spectrum analysis, X-ray diffractometry, and EPMA. By comparison of ambient vacuum pressure during deposition and the saturated vapour pressure of source metals, this method was considered to utilize the sublimation phenomenon.

1. Introduction

Recently, the power electronics module with higher voltage and larger current is demanded, and it is exposed to be used the ceramics semiconductors, e.g. SiC, AlN, or GaN, which should be cooled to proper temperature [1]. One of the cooling approaches is soldering ceramics semiconductors chip to graphite with high heat conductivity. The ceramics and graphite, however, have low wettability to molten liquid metals [2] and are difficult to join by soldering. Therefore the surface modification of their surface to wet with the molten metals is required. In this research, a new method for the metalizing ceramics and graphite is proposed. The ceramics and graphite are heated with the source metals simultaneously in the alternating magnetic field in vacuum. They are heated up at the temperature lower than the melting point of the source metals. In this work, the possibility of metallizing by the induction heating (IH) is newly clarified for the various combinations of the target materials and the source metals.

2. Experimental details

Deposition substrates were graphite, AlN and Si₃N₄ with the dimensions of 10×10×3 mm, and source metals were Al, Cu, Cr, Ni, Ti and 18-8 austenitic stainless steel (in the following, SUS304). Both deposition substrates and source metals were cleaned in the ultrasonic cleaner with ethanol bath. As shown in figure 1, a target plate was put on a metal source plate, where a W foil spacer was inserted between the mating surfaces. For SUS304 source heated lower than 1623 K, no spacer was inserted. The specimens were heated by induction heating in the vacuum atmosphere of 1.33×10⁻² Pa by applying approximately 10 kHz AC current. The heating temperature and the holding time are shown in table 1.
For comparison, the specimens in the same configuration were heated in a vacuum furnace by radiation heating.

The deposited layer on the target surface was observed by SEM, and analyzed using the Auger electron spectroscopy (AES) and EPMA. Some deposited layer was analyzed using XRD.

3. Results

The appearance of deposited layer of SUS304 source and Cu is compared by heating methods in figure 2. On the case of SUS304 source, both the deposited surfaces by induction heating and radiation heating were covered by the light gray material with slight difference. On the other hand, by Cu source, apparently, the amount of the deposition was different by heating methods. The deposited layer by induction heating seemed thicker. These results suggest that the deposition ability will different among the combinations of deposition substrates and source metals.

It is shown in table 2 that the deposition ability by this induction heating method with variations in deposition substrates and source metals. By Al source, no deposition was observed on any deposition substrates in appearance. By Cu source and Ni source, pure Cu and pure Ni were deposited on all the deposition substrates respectively, which was identified by AES. By Cr source, pure Cr was deposited on graphite plate, which was identified by XRD. By Ti source, XRD revealed that pure Ti and TiC were deposited on graphite substrate (figure 3(a)). By SUS304 source, Cr₇C₃ was deposited on graphite surface. It was identified by XRD (figure 3(b)). EPMA analysis indicated the compositions of the deposited layer by SUS304 source was 42.2Fe-37.7Cr-9.7Mn (in mass%) without Ni.

Secondary electron images of the deposited surfaces are shown in figure 4. On the case of Cu source, the round mounds were observed. It was considered that the deposited particles grew and coalesce each other. On the case of Cr source and Ti, the growth of the crystals was apparently observed. By Ni source and SUS304, the fine and random morphology was formed.

Figure 5 shows the difference in morphology among the combinations of sources and substrates. Both Cu source and Ni was not deposited in the form of crystal growth on all substrate. But on the case of Cu source on Si₃N₄, short whiskers grew.

4. Discussions

The deposition ability among the combinations of source metals and deposition substrates attempted in this research could be explained by the comparison of ambient pressure and saturated vapor pressure. In figure 6, the curves of saturated vapor pressure of source metals with temperature are plotted. The...
hatched box at $10^{-3} - 10^{-2}$ Pa indicates the range of ambient vacuum pressure. For Al source, its vapor pressure at the deposition temperature was lower than the ambient vacuum pressure. Therefore, Al was not deposited on all the substrates. On the other hand, for Cr, Ni and Ti sources, their vapor pressure values were higher than the ambient vacuum pressure, and their deposited layer was obtained for all the substrates. On the case of 18-8 austenitic stainless steel, SUS304, Ni’s vapor pressure value at the
deposition temperature is an order of magnitude lower than Cr’s value. So, the deposition layer by SUS304 might not contain Ni. As just described, because the deposition ability can be explained by the saturated vapor pressure, it can denote that the deposition mechanism of this method by induction heating utilizes the sublimation of metals.

This surface modification method using induction heating can be considered a type of PVD. A different point between this method and other PVD methods is that the evaporating method of source metal is the sublimation of metals. That means the source metals are not necessary to melt. Another different point is the distance between a source metal and a substrate is very small or none. According to these different points, this surface modification method using induction heating might have an advantage that the process could be conducted at relatively lower temperature with high deposition rate. The process temperature of this method might not be lower than that of sputter deposition, electron beam deposition, and laser beam deposition, but it will be lower than evaporative deposition by electrical
resistive heating. The deposition rate of this surface modification method requires further research, but it is expected to be high due to the narrow gap between a source metal and a substrate.

5. Conclusions
It was proposed that the new surface modification method for graphite and ceramics using the induction heating. The combinations of source metals and deposition substrates were examined and the applicability of this method was shown. And the following conclusions were obtained.
(1) The deposition did not depend on the target materials but the source materials.
(2) High vapor pressure of source metals makes deposition easier and it suggested this modification was conducted through the sublimation from the solid source material.
(3) Deposition films of Graphite/SUS304 and Graphite/Ti were detected carbide. Deposition films of Cu, Cr and Ni were pure.

References
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