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ARTICLE

Interfacial Structure and Mechanical Properties of Diamond/Copper Joint Brazed by Ag-Cu-In-Ti Low-Temperature Brazing Filler

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Abstract: Ag-Cu-In-Ti low-temperature filler was used to braze the diamond and copper, and the effects of brazing temperature and soaking time on the microstructure and mechanical properties of the joints were investigated. In addition, the joint formation mechanism was discussed, and the correlation between joint microstructure and mechanical performance was established. Results show that adding appropriate amount of In into the filler can significantly reduce the filler melting point and enhance the wettability of filler on diamond. When the brazing temperature is 750 °C and the soaking time is 10 min, a uniformly dense braze seam with excellent metallurgical bonding can be obtained, and its average joint shear strength reaches 322 MPa. The lower brazing temperature can mitigate the risk of diamond graphitization and also reduce the residual stresses during joining.

Key words: diamond microwave window; vacuum brazing; Ag-Cu-In-Ti; microstructure; mechanical properties

With the urgent need for sustainable development, the development of more efficient and sustainable energy sources has become a research focus[1–5]. Fusion energy with its advantages of low carbon emission, high energy output ratio, and low radiation is emerging as a focal research point, showing great potential[6–8]. In fusion devices, the microwave window plays a crucial role in energy transmission. Owing to the high-temperature and high-radiation environments where the microwave windows operate, the materials must have excellent thermal conductivity and dielectric properties[9–12]. Diamond has outstanding dielectric properties, mechanical strength, and high thermal conductivity (up to 2000 $W\cdot m^{-1}\cdot K^{-1}$ for single-crystal diamond), gradually becoming the ideal material for the fabrication of microwave windows and showing great potential in the renewable energy industry[13–14].

However, significant discrepancy in thermal expansion coefficient and thermal conductivity between the diamond and common metals or alloys pose considerable technical challenges to achieve effective bonding between the diamond and metals[15–19]. The sp3-hybridized covalent bond structure of diamond induces high interfacial energy with ordinary metals, resulting in difficulty to achieve strong metallurgical bonding using conventional methods[20–21]. Currently, brazing methods for diamond/metal bonding can be primarily divided into two types. (1) Indirect brazing, where metal film is deposited on the diamond surface, converting the diamond/metal joining to metal/metal joining. Metallization pretreatment can be applied to the diamond by coating with a metal layer before

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brazing[22–24]. (2) Direct brazing, where active-element-containing filler can enhance the wettability of filler on diamond. The commonly used fillers include Ag-Cu and Cu-based fillers with active element Ti and Ni-based fillers containing element Cr[25–26]. However, these conventional brazing methods have significant restrictions. Firstly, indirect brazing usually introduces an extra metallization pretreatment step, particularly for the large or complex components. Secondly, the Ni-based fillers used in direct brazing may lead to chemical corrosion or graphitization of the diamond, as Ni can act as a catalyst for diamond at high temperatures[27]. The brazing temperature for Ag-Cu and Cu-based fillers containing active Ti typically ranges from 800 ℃ to 900 ℃, which is relatively high and can cause graphitization and thermal damage to the diamond, therefore affecting the joint performance and reliability[28].

To address these issues, Ag-Cu-In-Ti active filler was proposed in this research for direct brazing method to achieve efficient bonding between diamond and copper at low temperatures. The active Ti in the filler can significantly enhance the wettability and activity of the filler on diamond. The addition of In can lower the melting point of the filler, reducing the brazing temperature and minimizing the thermal damage of diamond[29–30]. The risk of diamond graphitization decreases. This process offered a novel technical solution to achieve efficient brazing of diamond/metal joints at low temperatures.

1 Experiment

In this research, the chemical vapor deposition-prepared polycrystalline diamond with dimension of 5 mm×5 mm×1 mm and pure copper with dimension of 10 mm×10 mm×4 mm were used as the substrate materials. The filler was the Ag-Cu-In-Ti foil with thickness of 100 μm, and its composition was 59.2wt% Ag, 23.0wt% Cu, 14.5wt% In, and 3.3wt% Ti. As shown in Fig. 1a, differential scanning calorimetry (DSC) analysis result of the filler reveals that the solidus temperature is 686.5 °C and the melting point is 693.9 °C. Before brazing, the bonded surface of pure copper was polished by sandpaper to remove surface machining marks and oxide layers. The Ag-Cu-In-Ti foil was cut to sample of 5.5 mm×5.5 mm and lightly polished to remove the oxide layers. The diamond, copper, and foil were then ultrasonically cleaned by acetone, dried, and assembled. The experiment was performed using VAF-30 high-temperature vacuum furnace, which could maintain the vacuum level below 8×10^{-3} Pa throughout the process. During brazing process, the temperature was firstly raised to 300 °C for 30 min to remove the adhesive, then increased to 725–775 °C, and held for 5–15 min. Furnace cooling was applied until room temperature, as indicated in Fig.1b.

After brazing process, the samples were cut by 3D GREEN XL laser cutting machine coupled with electric discharge wire (EDW) cutting machine to observe the cross-section (Fig.1c). The samples were then mechanically ground by diamond grinding disc, followed by polishing with diamond suspension. Scanning electron microscope (SEM) was used to observe the microstructure of the braze seam, and energy dispersive spectroscope (EDS) was employed to analyze the element composition and distribution in typical regions.

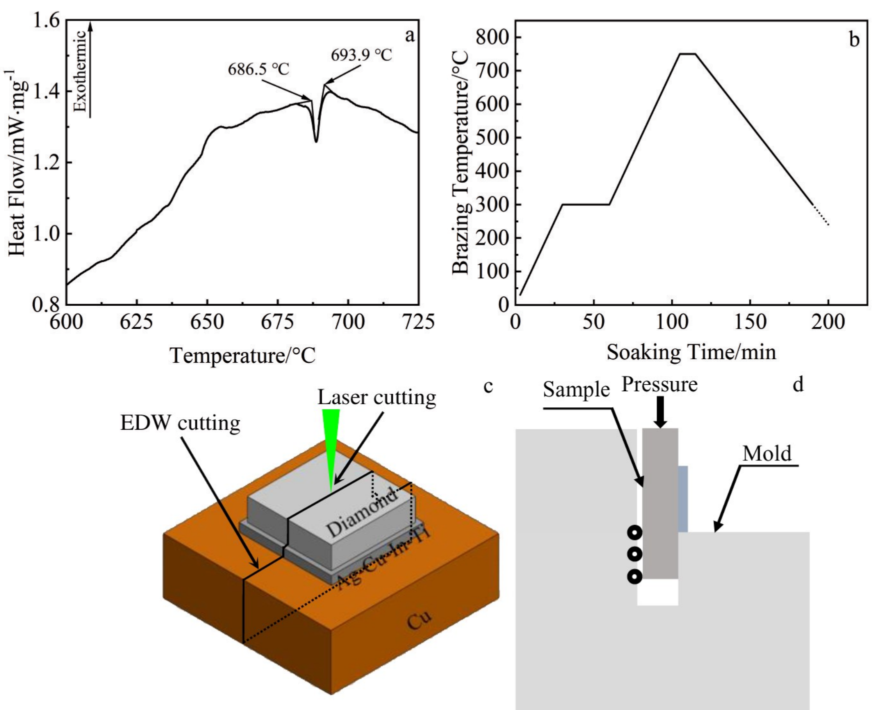

Fig.1 DSC curve of Ag-Cu-In-Ti filler (a); thermal cycle profile during brazing treatment (b); schematic diagrams of SEM sample preparation (c) and shear fixture (d)

Room-temperature shear strength tests were conducted on the brazed joints prepared under different brazing conditions using a universal testing machine (MTS CMT4204), as shown in Fig.1d. Fracture surfaces were also observed.

2 Results and Discussion

2.1 Typical microstructure of diamond/Ag-Cu-In-Ti/Cu brazed joint

Fig. 2a shows the typical microstructures of the diamond/Ag-Cu-In-Ti/Ag-Cu-In-Ti/Cu joint brazed at 750 °C for 10 min. It can be seen that the braze seam consists of white matrix phase A, gray phase B, light gray blocky phase C, and dark gray blocky phase D, as marked in Fig. 2a. Fig. 2b provides magnified image of the rectangular area in Fig. 2a, showing a nanometer-scale film E at the diamond/Ag-Cu-In-Ti filler interface. A jagged braze seam/Cu interface can be observed, indicating significant element exchange between the interlayer and Cu substrate. The braze seam with no obvious defects can be obtained with the Ag-Cu-In-Ti filler, indicating good wettability of the filler on diamond and effective metallurgical connection within the joint.

Fig. 3a – 3f present the element distributions of a typical diamond/Ag-Cu-In-Ti/Cu brazed joint. As seen in Fig. 3d and 3e, the elements In and Ti in the filler diffuse throughout the entire braze seam. Additionally, partial Ti is combined with Cu and In within the braze seam whereas other Ti diffuses towards the diamond/braze seam interface (Fig.3e). Ti exhibits a high affinity to carbon, producing a Ti-rich reaction layer at the diamond/braze seam interface.

Table 1 presents the composition of characteristic regions of the typical diamond/Ag-Cu-In-Ti/Cu brazed joint. The white phase A predominantly contains Ag. Considering the solubility of Cu and In in Ag, it is inferred that this region primarily consists of Ag(s,s). The gray blocky phase B and the light gray blocky phase C have similar contrasts, both containing a large amount of Cu. However, phase B is located near the edge of braze seam, which is closer to the Cu substrate, whereas the phase C is situated in the central portion of the braze seam, which is greatly influenced by the initial filler metal composition. Phase B has a higher Cu content compared with phase C, whereas phase C contains more In and Ti. Based on this result, it is inferred that both regions are primarily composed of Cu(s, s). Furthermore, considering atomic ratios and the results in Ref.[31–32], it is suggested that phase C also contains Cu_2InTi intermetallic compounds (IMCs). The dark gray blocky phase D is

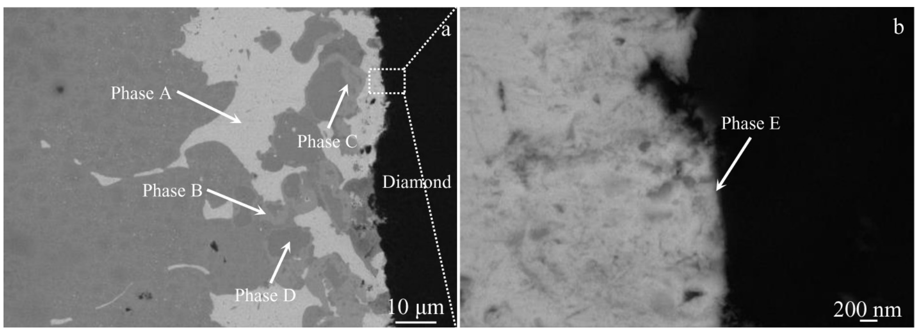

Fig.2 Typical microstructures of diamond/Ag-Cu-In-Ti/Cu joint brazed at 750 °C for 10 min

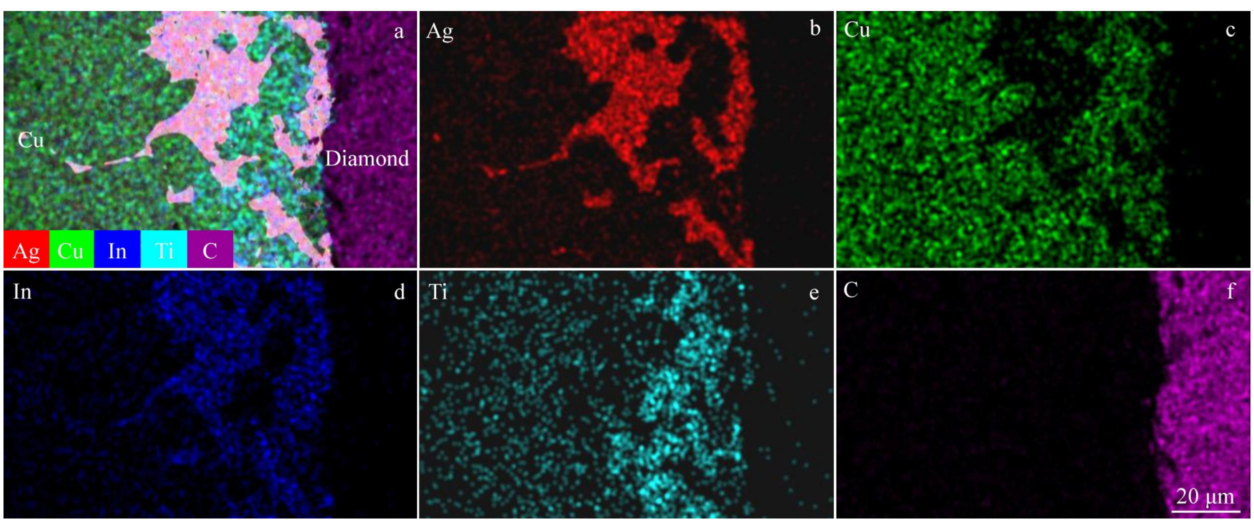

Fig.3 Element distributions of diamond/Ag-Cu-In-Ti/Cu joint brazed at 750 °C for 10 min: (a) overall element distribution; (b) Ag; (c) Cu; (d) In; (e) Ti; (f) C

Table 1 EDS composition results of phases marked in Fig.2 (at%)

Phase	Ag	Cu	In	Ti	C	Component
A	80.53	8.91	10.25	0.31	-	Ag(s,s)
B	1.74	98.15	0.11	-	-	Cu(s,s)
C	1.69	56.94	18.37	23.00	-	Cu_2InTi
D	1.28	79.11	0.09	19.53	-	Cu-Ti
E	0.11	0.89	0.03	13.72	85.26	TiC

primarily composed of Cu with a minor amount of Ti and Ag. Due to the strong affinity between Ti and Cu as well as the relatively low formation energy required for Ti-Cu, it is likely that Ti-Cu is precipitated through reactions between Ti and Cu during cooling process[33–34]. Therefore, it is inferred that this region primarily consists of Cu(s, s) with a small number of Cu-Ti IMCs. The reaction layer E exhibits a discontinuous distribution: it is mainly enriched in Ti and C, forming TiC through the interfacial reaction.

The phase formation within the brazed joint is directly related to the reactions occurring within the interface during brazing process. The active element Ti in the filler reacts with carbon from the diamond surface during brazing process, forming a thin layer of titanium carbide (TiC) at the interface. This TiC layer significantly enhances the interfacial bonding strength owing to its high hardness and strong covalent bond, improving load transfer across the joint. In addition, Ti can also interact with Cu to produce Cu-Ti IMCs within the braze seam. The presence of Cu-Ti phase, as a reinforcement component, contributes to the mechanical strength of the joint through impeding the dislocation motion. Furthermore, the incorporation of In leads to the formation of Cu_2InTi IMCs. These uniformly dispersed Cu_2InTi plays a critical role in the microstructure refinement and enhancement of mechanical properties by providing additional barriers against crack initiation and propagation. Briefly, the brazed joints contain diamond/TiC interfacial reaction layer/Ag(s, s) +Cu(s, s) + Cu-Ti+Cu_2InTi/Cu.

2.2 Effect of brazing temperature on microstructure and mechanical properties of diamond/Ag-Cu-In-Ti/Cu brazed joints

During brazing process, the brazing temperature and soaking time are the two critical parameters influencing the microstructure and mechanical properties of joints. Fig. 4 shows the microstructures of the diamond/Ag-Cu-In-Ti/Cu joints brazed at different temperatures for 10 min. With the increase in brazing temperature, the thickness of braze seam is gradually decreased from approximately 70 μm to 30 μm. High temperature causes the Cu substrate dissolving excessively into the filler and accelerates the loss of the molten filler, resulting in the narrowed braze seam. Comparing Fig. 4a – 4f, it is observed that TiC interfacial reaction layer on the diamond side changes from a fragmented sparse structure to a dense banded structure with the increase in brazing temperature. Reasonably, high brazing temperature causes intense interfacial reaction, leading to a rapid increase in TiC layer thickness. Near the copper substrate, large blocky Cu(s, s) connects to the Cu substrate with the increase in brazing temperature. Extensive element diffusion is accelerated, leading to phase agglomeration and coarsening of Cu(s, s). When the brazing temperature is 725 °C, apart from Ag(s, s), the phases in the brazed seam primarily exhibit a banded structure. This may be ascribed to the insufficient brazing temperature, leading to a slower diffusion rate of In and Ti and then the formation of Ti-rich banded phases. Incomplete diffusion also leads to the appearance of dendritic structures, reducing the uniformity of the brazed seam. Further comparison reveals that the Cu(s, s), Cu-Ti, and

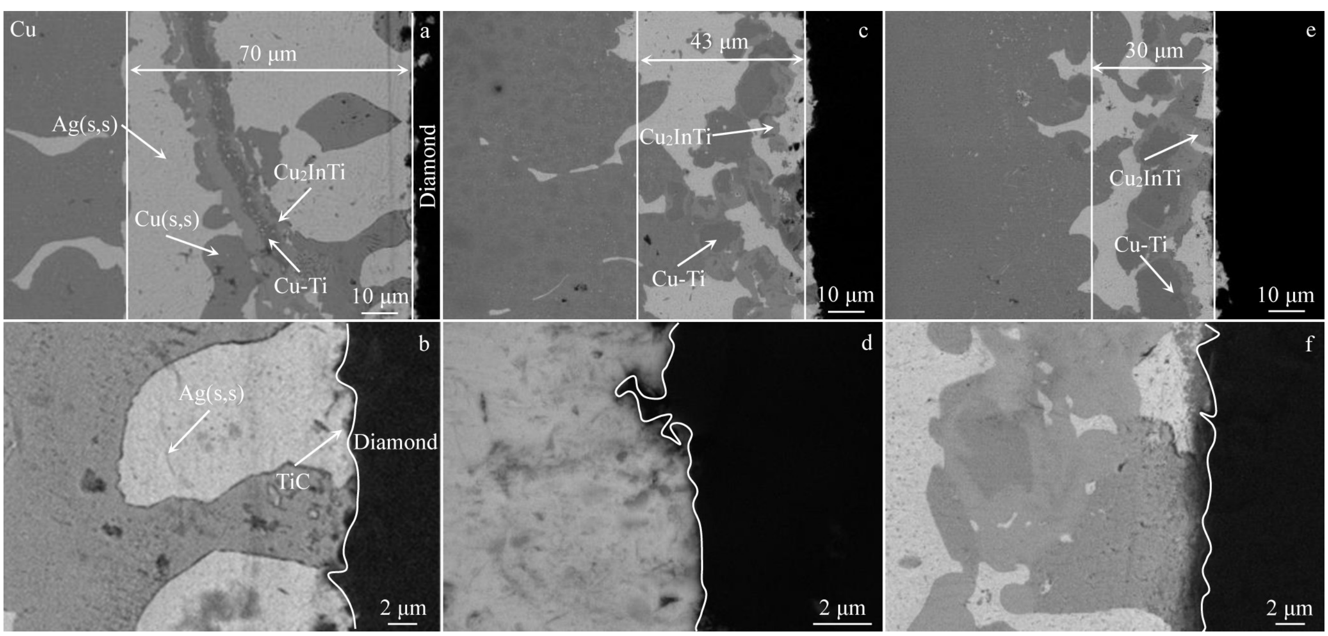

Fig.4 SEM images of diamond/Ag-Cu-In-Ti/Cu joints brazed at different temperatures for 10 min: (a–b) 725 °C, (c–d) 750 °C, and (e–f) 775 °C

Cu_2InTi IMCs in the brazed seam gradually grow from small fragmented pieces into large blocky structures with the increase in brazing temperature. As Ag diffuses extensively, the proportion of Ag(s,s) decreases in the braze seam.

The room-temperature shear strength of the brazed joints reflects the influence of the brazing process parameters on the mechanical properties of the joint. Average shear strength results of diamond/Ag-Cu-In-Ti/Cu joints brazed at different temperatures are shown in Fig. 5. When the brazing temperature increases from 725 °C to 750 °C, the average shear strength significantly increases from 231 MPa to the peak value of 322 MPa. When the temperature further increases to 775 °C, the shear strength slightly decreases to 307 MPa. Plastic deformation of different degrees is visible in the Cu substrate, and the failure primarily occurs near the diamond side.

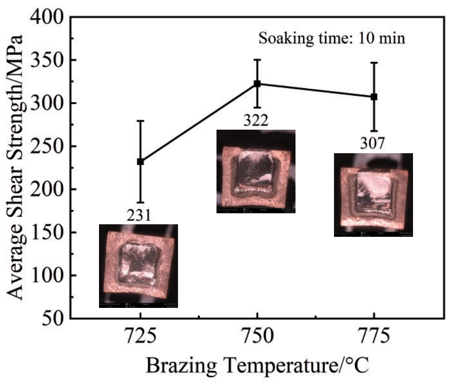

Fig.5 Average room-temperature shear strength of diamond/Ag-Cu-In-Ti/Cu joints brazed at different temperatures for 10 min

Fig. 6 shows the fracture morphologies of diamond/Ag-Cu-In-Ti/Cu joints brazed under different processing conditions. According to Fig.5, the fracture mainly occurs on the diamond side at 725 °C, although some cracks extend into the braze seam. As shown in Fig. 6a–6b, distinct tearing ridges can be observed, as well as clear river pattern, signifying the brittle fracture. This result suggests the mixed mode of ductile and brittle fracture when the brazing temperature is 725 °C. When the temperature rises to 750 °C, the fracture is entirely concentrated on the diamond side. Fig. 6c – 6d present smooth fracture surfaces with a large number of lamellar structures with cleavage planes, displaying characteristic of brittle fracture. The fracture remains primarily on the diamond side when the brazing temperature is 775 °C, but some cracks extend into the TiC reaction layer. Fig. 6f shows distinct cleavage planes and void defects, indicating brittle fracture mode. Overall, with the increase in brazing temperature, the shear strength of the joints is firstly increased and then decreased. When the joint is brazed at a lower temperature (725 °C), Ti diffusion is slow, and interfacial reactions are insufficient, leading to weak bonding between the diamond and filler. Additionally, the Cu(s, s) and Cu-Ti IMCs in the braze seam are unevenly distributed with a layered structure, leading to low joint shear strength. When the joint is brazed at 750 °C, Cu_2InTi IMCs are finer and more dispersed, reducing microcrack formation contributing to the second-phase particle strengthening, and thereby improving the mechanical properties of the joint. With the further increase in brazing temperature, the silver-white area in the fracture surface is increased,

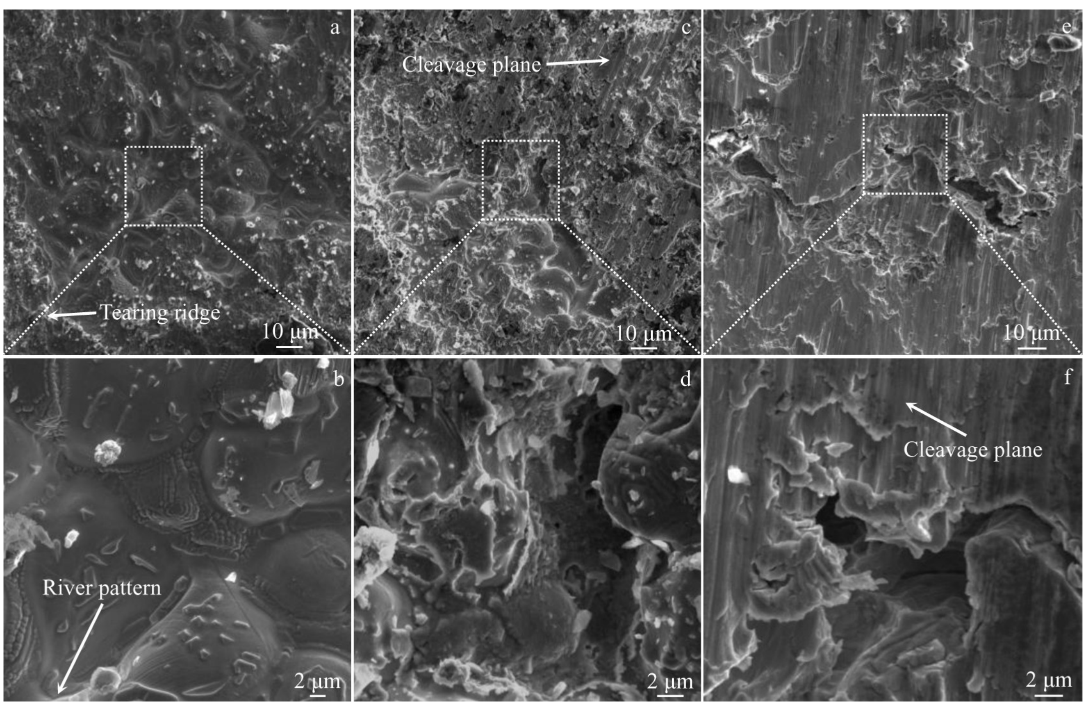

Fig.6 Fracture morphologies of diamond/Ag-Cu-In-Ti/Cu joints brazed at different temperatures for 10 min: (a–b) 725 °C, (c–d) 750 °C, and (e–f) 775 °C

indicating a higher proportion of crack initiation within the reaction layer. High brazing temperature induces narrowed braze seam, growth of Cu(s, s) and Cu-Ti IMCs, and coarsening of Cu_2InTi IMCs, ultimately leading to the reduction in joint shear strength.

2.3 Effect of soaking time on microstructure and mechanical properties of diamond/Ag-Cu-In-Ti/Cu brazed joints

Fig.7 shows the microstructure changes of diamond/Ag-Cu-In-Ti/Cu joints brazed for different soaking time. When the brazing temperature is 750 °C, the width of the braze seam is gradually decreased from approximately 85 μm to around 26 μm with the prolongation of soaking time from 5 min to 15 min. Prolonging soaking time leads to excessive dissolution of the Cu substrate towards the filler, intensifying the filler depletion and contributing to the narrowed braze seam. It is also observed that with the prolongation of soaking time, the TiC reaction layer at the diamond/Cu interface gradually becomes denser, which is transformed from fragmented sparse layered structure to the continuous layer structure, and the thickness is increased to approximately 400 nm when soaking time is 15 min. When the soaking time is short, the diffusion of Ti is insuffcient, and the interfacial reaction between Ti and carbon within the diamond is inadequate, resulting in inferior metallurgical bonding. Furthermore, long soaking time causes intense interfacial reactions, resulting in the thickening of TiC layer. Comparing Fig. 7a – 7f, Cu from the oxygen-free substrate gradually dissolves into the molten filler, as well as brittle phases, such as Cu-Ti and Cu_2InTi in the braze seam. Besides, with the prolongation of soaking time, the phases in the braze seam suffer a transition from the fragmented structures to large blocky structures. Generally, the longer the soaking time, the more the large blocky phases, the narrower the braze seam, the coarser the structures, and the more the brittle phases, such as Cu-Ti and Cu_2InTi. These phenomena all have significant effect on the mechanical properties of the brazed joint.

Fig.8 shows the effect of soaking time on the average shear strength of diamond/Ag-Cu-In-Ti/Cu brazed joints. It is evident that the effect of soaking time on the joint shear strength is similar to that of brazing temperature. With the prolongation of soaking time, the average shear strength is initially increased and subsequently decreased. Plastic deformation of different degrees exists in the Cu substrate and the failure primarily occurs near the diamond side

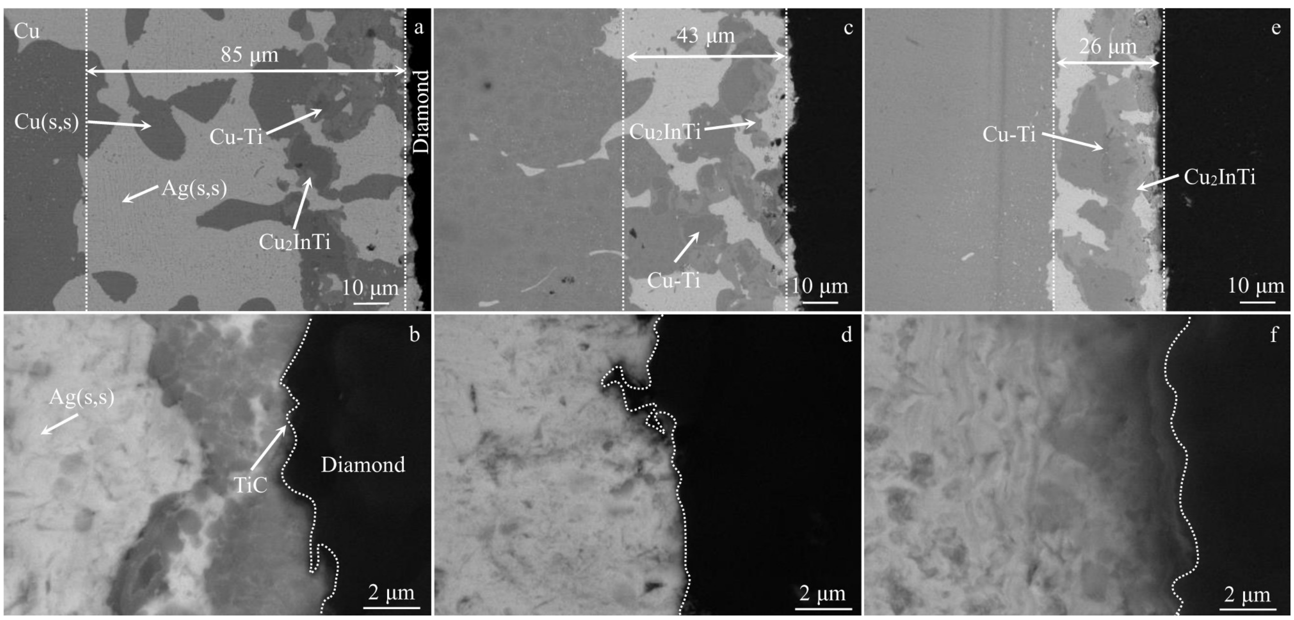

Fig.7 SEM images of diamond/Ag-Cu-In-Ti/Cu joints brazed at 750 °C for different soaking time: (a–b) 5 min, (c–d) 10 min, and (e–f) 15 min

Fig.9 shows the fracture morphologies of diamond/Ag-Cu-In-Ti/Cu joints brazed for different soaking time. When the soaking time is 5 min, the fracture mainly occurs on the diamond side, and some cracks extend into the braze seam. As shown in Fig.9a–9b, when the soaking time is 5 min, a few tearing ridges can be observed, indicating ductile fracture, and the distinct cleavage planes indicate the brittle fracture. This

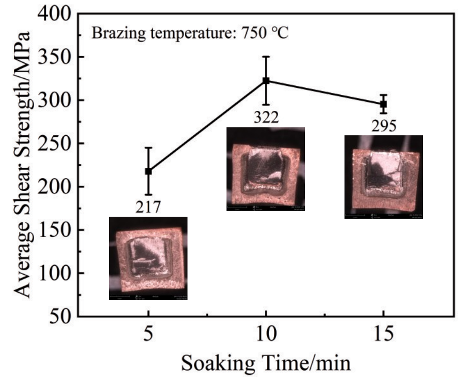

Fig.8 Average shear strength of diamond/Ag-Cu-In-Ti/Cu joints brazed at 750 °C for different soaking time

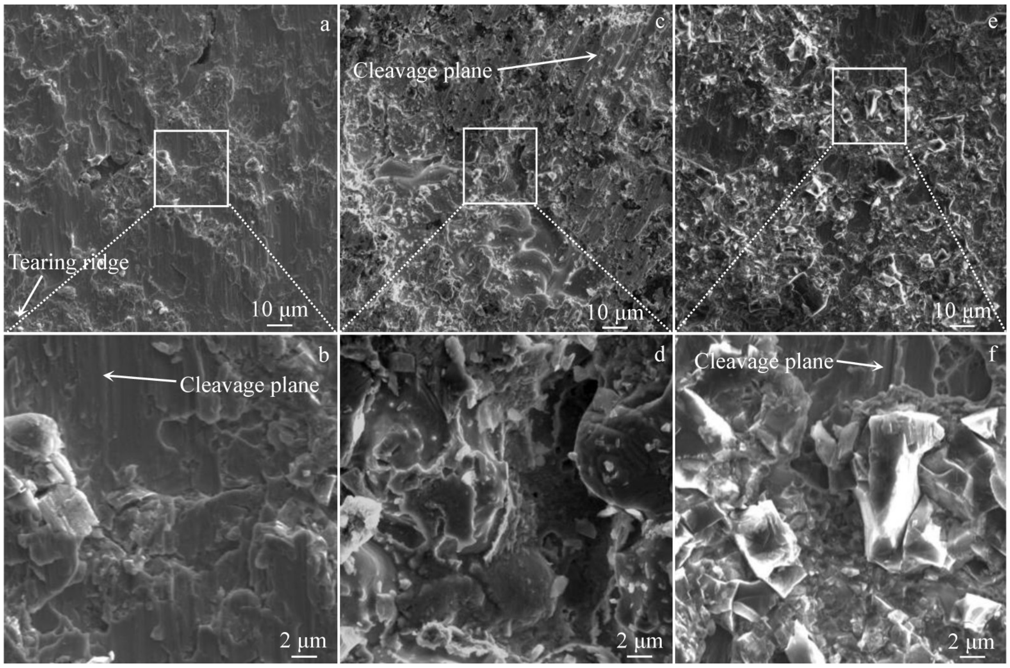

Fig.9 Fracture morphologies of diamond/Ag-Cu-In-Ti/Cu joints brazed at 750 °C for different soaking time: (a–b) 5 min, (c–d) 10 min, and (e–f) 15 min

result suggests the mixed fracture mode of ductile and brittle fracture. Fig. 9c – 9d show that when the soaking time is 10 min, the fracture is concentrated on the diamond side, indicating the brittle fracture mode. Finally, when the soaking time is 15 min, the fracture still primarily occurs on the diamond side, and some cracks extend into the TiC reaction layer. According to Fig.9e–9f, distinct cleavage planes can be observed, indicating the brittle fracture characteristics. With the prolongation of soaking time, molten filler loss is intensified, and the braze seam is gradually narrowed. At the same time, the precipitation of brittle phases, such as TiC and Cu_2InTi, is promoted within the braze seam, reducing the plasticity and toughness. These phenomena result in the decrease in shear strength of joints when the soaking time is 15 min. Therefore, the optimal brazing processing parameters are determined as brazing temperature of 750 °C and soaking time of 10 min.

The formation of Cu_2InTi and Cu-Ti IMCs significantly influences the fracture behavior of brazed joints. Initially, the fine and uniformly distributed Cu_2InTi and Cu-Ti particles contribute to the dispersion strengthening, enhancing the overall strength and toughness of the joints by hindering microcrack propagation. However, when these IMCs become coarse, their brittleness reduces the overall strength of the joints. Particularly, the coarse Cu_2InTi particles promote the crack initiation under mechanical loading owing to inherent brittleness. During shear strength testing, the cracks are more likely to propagate along the interfaces of the coarse IMCs or through the brittle phases, thereby reducing the toughness. Hence, controlling the size and distribution of the Cu_2InTi and Cu-Ti IMCs is essential for optimization of the fracture resistance of the joints.

3 Joining Mechanism of Diamond/Ag-Cu-In-Ti/Cu Brazed Joints

The bonding mechanism of diamond/Cu joints brazed by Ag-Cu-In-Ti filler is presented in Fig. 10. Firstly, when the brazing temperature rises above the melting point, the brazing filler begins to melt, introducing the liquid into the braze seam. With the increase in brazing temperature, Ti continues to diffuse into the liquid and then dissolves into the molten filler. Therefore, the Ti content in the liquid gradually increases. The dissolved Ti is adsorbed on the diamond surface and reacts with the carbon atom from the diamond, thereby forming TiC. Due to the low critical Ti content for TiC precipitation, a continuous TiC reactive layer forms on the diamond surface. Other Ti atoms are aggregated to form a Ti-rich region. Because Ti has a high affinity to Cu, Cu-Ti IMCs form in the braze seam. The surface free energy of In is lower than that of Ti, which leads to preferential reaction with Ag and Cu during brazing process. Most In dissolves into Ag(s, s) or Cu(s, s), and small part of In is combined with Ti and Cu to produce the Cu_2InTi IMCs. During cooling process, Ag and Cu firstly solidify, producing the Ag(s, s) and Cu(s, s) in the joints. As the solubility of Ti in Cu(s,s) decreases, some Cu-Ti IMCs are also aggregated.

The key factors affecting the strength of diamond/metal brazed joints should be ascribed to the residual stresses, interfacial bonding strength, and interlayer strength. For the diamond/Cu joints, the interface bonding strength depends on the TiC reaction layer. When the brazing temperature is low (for example, 750 ° C) or the soaking time is short (for example, 5 min), the diffusion rate of Ti is slow, resulting in insufficient reaction, forming a discontinuous TiC reaction

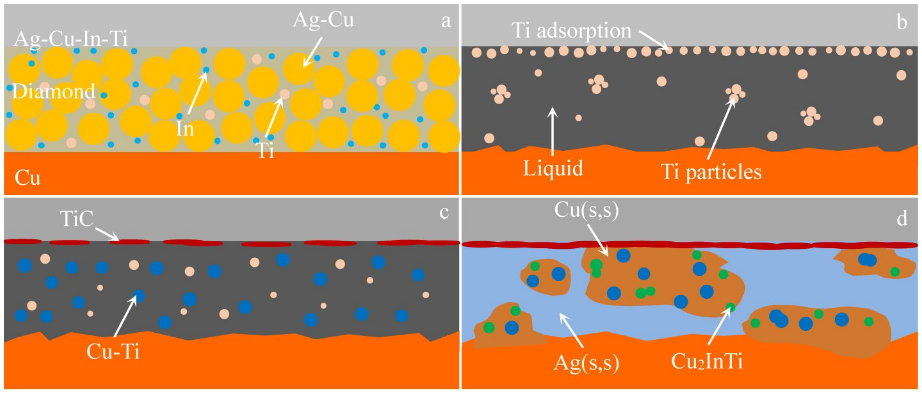

Fig.10 Schematic diagrams of formation mechanism of diamond/Ag-Cu-In-Ti/Cu brazed joints: (a) before brazing; (b) brazing material melting and Ti diffusion; (c) formation of TiC, Cu-Ti, and Cu_2InTi; (d) final joint morphology

Table 2 Comparison of shear strength of different diamond/metal joints brazed by different fillers

Base material	Processing condition	Filler (wt%)	Shear strength/MPa	Ref.
Diamond/copper	750 °C/10 min	AgCu-10Sn-1Ti	256.1	[21]
Diamond/copper	820 °C/15 min	96(Ag-28Cu-10Sn)-4Cr	147.0	[35]
Diamond/316L	880 °C/10 min	Cu14.4Sn10.2Ti1.5Zr	321.0	[36]
Diamond/1045 steel	880 °C/20 min	Ag45Cu20In5Ti	250.0	[37]
Diamond/copper	750 °C/10 min	AgCu-14.5In-3Ti	322.0	This work

layer at the interface, and thereby weakening the bonding force between the diamond and interlayer. Ti is gathered in the center of braze seam to form Ti-rich strip residual phases, resulting in inferior microstructure uniformity of the joints. With the increase in brazing temperature or the prolongation of soaking time, the interfacial reaction becomes more adequate, and a continuous uniform TiC layer without cracks and defects is formed at the diamond interface. The TiC layer with mixed metal bonding and covalent bonding improves the bonding strength. Moreover, some formed Cu_2InTi and Cu-Ti IMCs are relatively fine and evenly distributed, which can reduce the formation of microcracks and improve the strength of braze seam through dispersion and fine-crystal-strengthening effects. When the brazing temperature further increases (for example, 775 °C) or the soaking time is prolonged (for example, 15 min), the interfacial reaction layer is thickened, whereas the brittle and hard IMCs (Cu_2InTi) are increased. The resultant joints are brittle, resulting in the reduction in the shear strength.

Table 2 shows the comparison of the shear strength of different diamond/metal joints. In this research, the joint bonding strength is 322 MPa, which is the highest value in Table 2. Compared with the conventional fillers, such as Cu-Sn-Ti and Ag-Cu-based fillers, Ag-Cu-In-Ti filler has unique benefits. The addition of In effectively lowers the melting point of the filler to approximately 694 °C, achieving the low-temperature brazing process. This reduction in brazing temperature minimizes the thermal damage to the diamond, such as graphitization, and decreases the residual stresses caused by the mismatch in the thermal expansion coefficients between the diamond and copper, which is critical for the fabrication of diamond microwave windows[23]. In addition, the Ag-Cu-In-Ti filler promotes the formation of fine homogeneous IMCs through optimal brazing process, enhancing the interfacial bonding and mechanical strength. The joints brazed with Ag-Cu-In-Ti filler exhibit higher shear strength than those brazed with traditional fillers, indicating that Ag-Cu-In-Ti filler has superiority for diamond/metal brazing applications. Overall, not only the graphitization problem can be avoided, but also the long-term stability of the joints is guaranteed, providing significant technical and theoretical support for the manufacture of diamond microwave windows for fusion reactors.

4 Conclusions

1) The high-quality diamond/copper joints can be prepared at low temperatures using Ag-Cu-In-Ti filler. The brazed joints contain diamond/TiC interfacial reaction layer/Ag(s,s)+Cu(s,s)+Cu-Ti+Cu_2InTi/Cu.

2) The brazing temperature and soaking time have significant effects on the microstructure of joints. With the increase in brazing temperature or the prolongation of soaking time, the TiC interfacial reaction layer becomes continuous and uniform, ensuring the reliable bonding between the diamond and interlayer due to the characteristics of metal and covalent bonding. The fine Cu-Ti and Cu_2InTi IMCs are

evenly distributed in the braze seam, producing the fine-crystal-strengthening effect. However, the high brazing temperature or long soaking time may lead to the increase in brittle hard phases, which therefore embrittles the joints.

3) With Ag-Cu-In-Ti filler, the joints achieve an average shear strength of 322 MPa after brazing at 750 ℃ and holding for 10 min. The addition of element In reduces the melting point of the filler, thereby lowering the brazing temperature. The residual stress is released, and the risk of diamond graphitization can also be avoided.

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Ag-Cu-In-Ti低温钎料真空钎焊金刚石/铜接头的界面组织和力学性能

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摘　要：使用Ag-Cu-In-Ti低温钎料钎焊连接金刚石和铜，研究了钎焊温度和保温时间对接头显微组织与力学性能的影响，探究了接头形成机制并构建了接头组织与力学性能的关联。结果表明：在钎料中加入适量的In能够显著降低钎料的熔点，增强了钎料对金刚石的润湿能力。当钎焊温度为750 ℃、保温10 min后，获得了具有良好冶金结合性能且均匀致密的钎缝组织，接头平均抗剪切强度达到322 MPa。较低的钎焊温度避免了金刚石石墨化风险，同时也降低了焊接残余应力。

关键词：金刚石微波窗；真空钎焊；Ag-Cu-In-Ti；微观组织；力学性能

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