Microstructural analysis of brazing sapphire and Inconel 600 for sensor applications

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The development of sapphire-based sensors for gas pressure application is growing in demand because of their appealing characteristics that could withstand high temperatures and harsh operating conditions. However, the joining process of sapphire to other materials, especially metals, is difficult to achieve because of dissimilar physical and mechanical properties. In this study, a direct brazing process was successfully demonstrated to bond sapphire to sapphire and sapphire to Inconel 600 using BAg-8 + 1.5Ti filler metal. Silver-based brazing filler metal with active element of Ti was believed to promote wetting in brazing of ceramic surfaces. The results have shown that a reaction layer is present between the sapphire and the brazed layer. There is also a variation in the phase formation between the sapphire/sapphire and the sapphire/Inconel 600 joints because of the influence of elements from the Inconel 600.

Keywords: Microstructure, Brazing, Sapphire, Inconel 600, Sensor, Reaction layer

Introduction
The development of high-temperature pressure sensor requires materials that possess high corrosion resistance and the ability to withstand elevated temperatures. Solid-state silicon pressure sensors are usually chosen because of their stability and repeatability readings and are successfully used in the chemical industry, process control and liquid pressure systems as well as switching devices. However, the utilisation of these sensors on liquids requires expensive oil-filled barrier diaphragm systems. There is also a requirement to coat the sensing media with an anti-corrosion film which is difficult to achieve. Recently, the development of sapphire-based sensors as an alternative to oil-filled silicon has shown promising results. Ishihara et al. reported the development of a sapphire-based pressure sensor chip which can resist up to 200°C of self-heating temperature and pressure performances are less than 0.1% full scale (FS). For similar sapphire-based capacitive pressure sensor, Soeda et al. have obtained extremely low-temperature-dependent sensitivity of 0.001% of FS per °C or less without any thermal compensation. Therefore, sapphire-based pressure sensors would have an impact in gas sensing applications, aerospace and automotive industries, particularly in high-temperature environments, in aggressive oxidising or reducing gas media.

The sensing media of a sapphire-based sensor is usually made from a single sapphire crystal adhered onto a metal body. To reduce mechanical stresses, the sensing medium can be mounted onto another sapphire interface before being bonded onto the metal. Nickel-based alloys are usually utilised as metal bodies, since they have high corrosion resistance. Thus, proper joining techniques must be considered in order to bond the sapphire to the metal body. Joining of sapphire to sapphire and sapphire to metal can be achieved using diffusion bonding and brazing techniques. Although the literature on the subject is limited, there are studies on brazing of sapphire to titanium, brazing of sapphire to hot pressed Al₂O₃ diffusion bonding of Cu to sapphire/alumina and platinum precipitates in sapphire. The results have shown that brazing can be achieved when using an active metal, such as Ti to form a reaction layer at the interface. It is speculated that the reaction layer would influence the joining strength as reported by Ning et al. and Liu et al.

In this study, direct brazing processes of sapphire to sapphire and sapphire to Inconel 600 were evaluated. The filler material used was an Ag-base filler metal foil containing 1.5 mass-% Ti. It was anticipated that by utilising this active filler metal for direct brazing would eliminate the need for the complex and expensive techniques of Mo-Mn metallisation processes currently in use for standard industrial process of sapphire brazing as mentioned by Valette et al. The microstructure observation of joined interface and interfacial reaction between sapphire/sapphire as well as sapphire/Inconel 600 joints were investigated in detail.

Experimental procedures
A high-purity single-crystal sapphire (99.999% Al₂O₃) in disc form with the diameter of 20 mm and 1 mm thickness

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