MULTILAYER CERAMIC SUBSTRATE -TECHNOLOGY FOR VLSI PACKAGE/ MULTICHIP MODULE

K. OTSUKA

CERAMIC RESEARCH AND DEVELOPMENT IN JAPAN

ELSEVIER APPLIED SCIENCE

Multilayer ceramic substrate-technology for VLSI package/multichip module

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Foreword

Dr. Kanji Otsuka graduated from the Department of Ceramics, Kyoto Institute of Technology in 1959 and the following year joined the staff of Hitach Co. Ltd. Since that time, he has worked and developed semiconductors, multilayers ceramic substrate and their devices. This book is one of the results of study by Dr. Kanji Otsuka.

Dr. Kanji Otsuka studied multilayer printed board made with alumina ceramics. Embedded printed wiring of metal was one of the subjects. The attainment of a wiring pattern with high accuracy is described in this book.

It is necessary to be cofired between alumina and tungsten metal powder. Therefore the firing shrinkages between the ceramics and metal powder need to be matched and be simultaneously made up to the final dimensions of design values. These controls are done by the ceramic porocity adjustment. Powder arrangement and the characteristics of bulk density and air permeation in the green forming ceramics should consequently be well under control.

Many parameters underlying this composite structure must be in the optimization. Therefore, quantitative scientific analysis in each process and these relations are needed. This book illustrates this point and leads to a guide line for the fine products.

I recommended him to publish his results as a book style, because this book promotes R & D of multilayer ceramic substrates for semiconductors and computer usage. This book is recommended to students, researchers and engineers in the fields of electronic ceramics, makers and users, all over the world, developed countries and underdeveloped countries because as for starting materials, he used natural raw materials. I am sure this book will prove to be a milestone in the field of ceramic multilayer substrates.

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1 | Introduction

1.1 INTRODUCTION

Recent developments in computers, computer peripherals and electronic consumer products owe much to the development of semiconductor devices, namely ICs and LSIs. There have also been considerable developments in the technology for incorporating these LSIs into equipment. Wiring substrates are particularly important as components for connecting semiconductor devices with each other and with input/output devices. To enable high-speed signal exchange, the wiring on wiring substrates needs to be short. In order to achieve this, fine wiring techniques become necessary to decrease the horizontal surface of the wiring substrates; this also fulfils the need for size reduction. The development of highly integrated high performance LSIs also entails the necessity for raising the wiring density of wiring substrates, leading to the wide adoption of multilayer wiring.

Techniques for producing fine and highly integrated (multilayer) wiring substrates have received a lot of effort. Broadly speaking there are two types of so called printed circuits, employing glass-fibre-reinforced epoxy resin boards and copper metallization; and multilayer ceramic wiring substrates, with tungsten or molybdenum metallization on alumina ceramic. The former type is used for applications requiring wiring over a relatively large surface area; the latter type is mainly intended for applications requiring small highly-integrated wiring systems. The upshot of this distinction is that microfine processing is more advanced for the latter type than the former type, and the method for making the latter type is more suited to fine processing. This book is concerned with the latter type-multilayer alumina ceramic wiring substrates, and with systematic studies into improving dimensional precision, and into techniques for metallization.

In making multilayer alumina ceramic wiring substrates, preforms already furnished with metallized wiring are hardened by passing though a firing process. At this time they shrink by 10% or more; in terms of surface area there is a large shrinkage of something under 30%. Variations in this shrinkage are reflected in variations in the dimensions of the finished products, and this hinders the production of high-precision fine wired packages for semiconductors. Because the metallized wiring is also fired, it is necessary to have some means for preventing the oxidization of the metal making up the metallized wiring (firing in a reducing atmosphere), but this also hinders the loss of the organic binder employed when making the preform. In the preform, the ceramics and the metallization are both in the form of powders held firm by binders, and the filled state differs with the particle size of the

Table 1.1. Typical Cermic Materials for the LSI Packages and Boards

Materials	*Composition*	*Thermal coefficient of expansion 0–100°C (10^{-6} °C^{-1})*	*Thermal conductivity (W/m · K)*	*Dielectric constant/ MHz*	*Young's modulus (GPa)*	*Modulus of rupture (MPa)*
Alumina	Al_2O_3 92–95% SiO_2, MgO etc	6.0–6.5	15–30	8.5–9.5	270–380	300–350
Silicon carbide	SiC > 99%	3.5	150–270	40	420	450
Aluminum nitride	AlN > 99%	4.0	100–170	8.5–9.0	320	450
Mullite	$3Al_2O_3.2SiO_2$, SiO_2, CaO etc	3.6–4.0	4–6	5–6.8	180	80–200
Glass-ceramics	Borosilicate glass and alumina	3.5–4.0	3–7	5–7	160–200	80–200

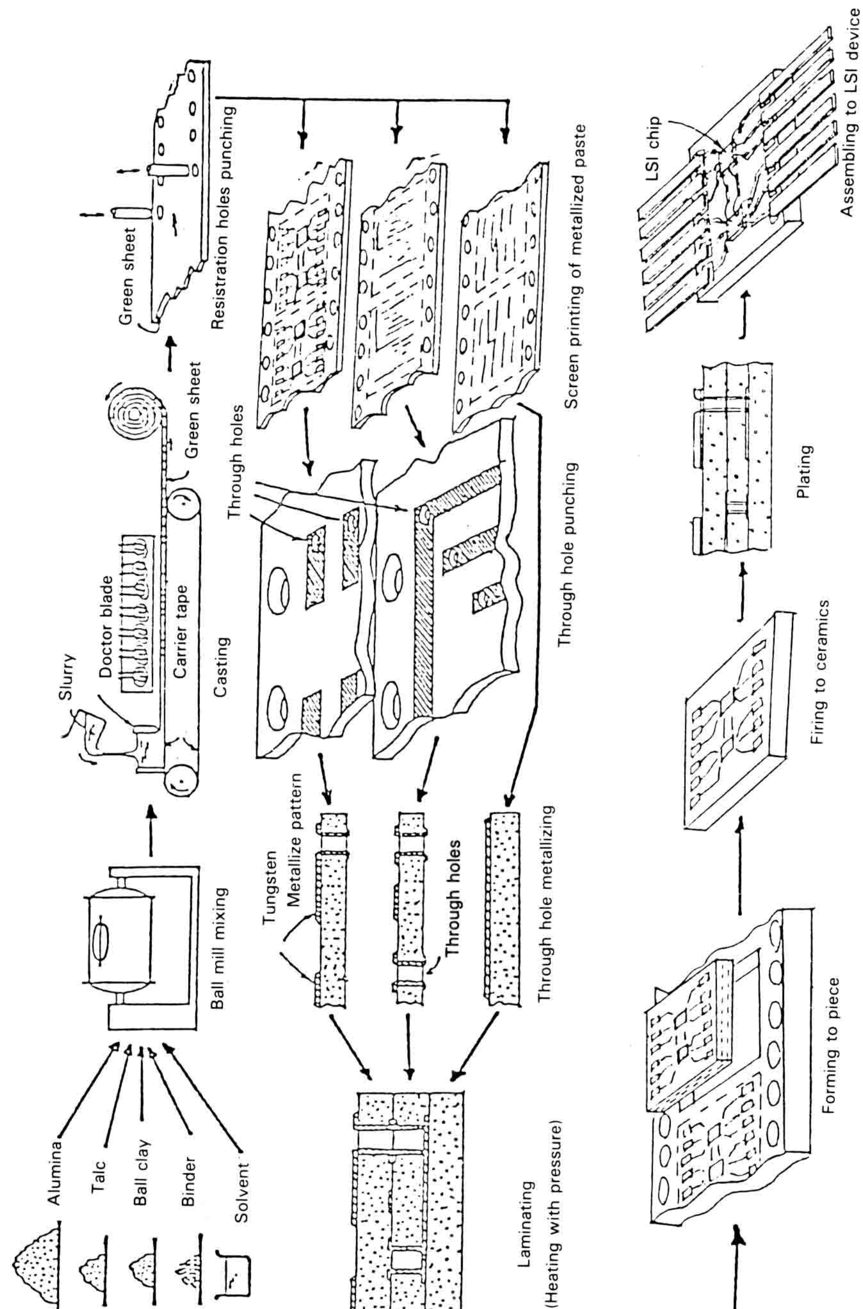

Fig. 1.1. Production Process for multilayer package of LSI's.

powders and the state of mixing. Many factors, such as the sintering reaction of the powder, binding between the ceramic and the metallization, and the degree to which shrinkages are matched, etc., during firing contribute to variations in dimensions. When it comes to optimizing the system as a whole, trade-offs are necessary among these various factors. To date there have been few theoretical or practical studies concerned with these systems as a whole, so this was the main thrust of this research. Because raising dimensional precision affects the strength of metallization bonding, studies were also undertaken on the conditions for obtaining this strength and on the mechanism of bonding. Additional studies concerned suitable ways to protect the insulation of metallization arranged with very small gaps and to prevent it from breaking down.

1.2 PAST AND CURRENT STUDIES

The concept of alumina ceramic multilayer circuit boards was announced by Gyurk and Liederbach (1960), incorporating the current processing method (green sheets being produced using a doctor blade and lamination of sheets with metallized patterns). Since the announcement of this method, this technology has been that normally employed for advanced substrates for semiconductor elements. Stetson and Schwartz (1961) developed this concept, and announced an idea for enabling complex and free wiring bonding, in which wiring, embedded in a layered structure, intersected in three dimensions. Liederbach and Stetson (1961) gave examples of practical applications for this structure; and this concept has continued to the present time. The processes involved in the most common method are shown in Fig. 1.1 and the material possibility is listed in Table 1.1.

A lot of research has subsequently been carried out on improving this method of manufacture, improving the materials, etc. Alm and Miller (1966) proposed a method of copper impregnation, to overcome the drawbacks of molybdenum wiring materials, which cultivate porosity and have high electrical resistance. Schwartz and Wilcox (1967) enumerated the factors that need to be controlled in this method, and discussed the need for design optimization balancing all of these factors, singling out the main factors to control. Thus, by preparing and mixing particulate ceramic starting materials, a binder and a solvent, green sheets like paper are made

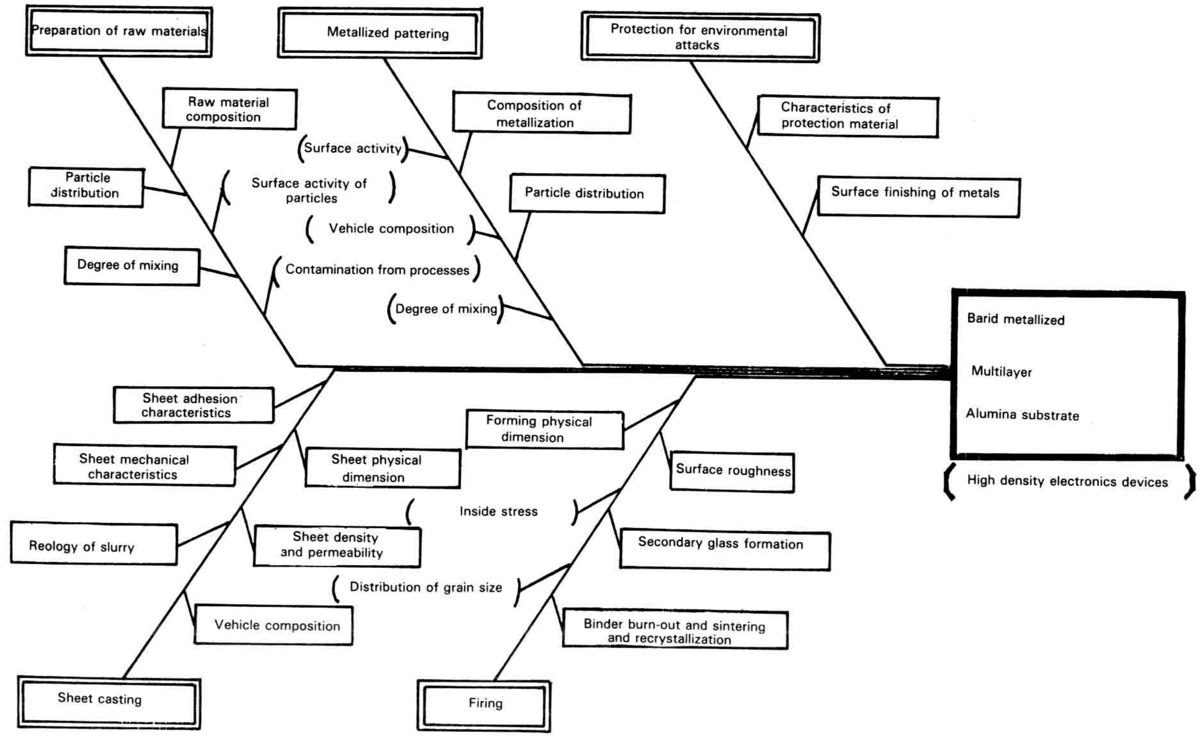

Fig. 1.2. Essential factors in high-precision processing of internal wired multilayered alumina ceramic wiring substrates with protecting structures. 1. Preparation of alumina starting materials; 2. Metallization; 3. Protection from the environment; 4. Starting material composition; 5. Metallization composition; 6. Protecting material characteristics; a. (degree of activity); b. (degree of activity of starting materials); c. (vehicle composition); d. (process contaminants); e. (degree of mixing); 7. Particle size distribution; 8. Metallization particle size; 9. Added metallization characteristics; 10. Degree of mixing; 11. Multilayer alumina ceramic substrates with internal metallized wiring, fitted with a protecting structure f. (devices with high density electronic circuits); 12. Sheet adhesion characteristics; 13. Product dimensions and shape; 14. Sheet mechanical properties; 15. Sheet dimensions and shape; 16. Surface roughness; g. (stresses within the complex); h. (grain size distribution); 17. Slurry rheology; 18. Sheet density and porosity; 19. Amount of glass recrystallization; 20. Vehicle composition; 21. Porosity after burn-out of organic binder; 22. Sheet processing; 23. Firing.

with a constant controlled porosity. As well as enabling metallizing paste to be printed without blotting, this is also beneficial when it comes to embedding the thickness of the metallized wires in the green sheet during lamination. Changes in porosity are caused by pressure during lamination, and in order to keep the changes uniform it is important to improve the flatness of the green sheets, i.e. improve precision with regard to thickness. By ensuring a constant degree of activation among particles in the aligned state before firing, variations in firing shrinkage can be kept within $\pm 1\%$. Metallizing materials are chosen which have a similar firing shrinkage and coefficient of thermal expansion to those of the ceramic, and which react well (sinterability) with the ceramic. Firing is carried out in a reducing atmosphere so as to prevent the oxidation of the metallization, and sintering is carried out after burning out the organic binder. And the control of particle size and pore size in the ceramic is important for obtaining stable firing shrinkage and strength. However, Schwartz and Wilcox do not deal in any way with quantitative aspects. The factors which are generally controlled at the present time, including the suggestions of Schwartz and Wilcox, are summarized in Fig. 1.2. Everett (1969) reported that with the above method the variation in firing shrinkage could be kept to $\pm 1\%$, and that fine wiring 100 μm wide could be printed, but there are no reports that this has actually been achieved. Keeping the variation in firing shrinkage small leads to improvements in the dimensional precision of the finished multilayer substrates (precision in the relative positioning of the wires), and is an important factor when it comes to making high-precision multilayer substrates, but in more than 20 years since the publication of these reports there have been no reports directly concerning the stabilization of shrinkage.

The inventor of the concept, Gyurk (1960), pointed out that substrate firing should be carried out in an atmosphere of reducing gas with water vapour to keep a balance between the promotion of binder burn-off and the prevention of metal oxidization, but he did not establish a firing temperature curve. Finch (1960) reported that binder burn-off required holding at a temperature of 600°C. It is now widely recognized that binder burn-off is difficult to accomplish in a reducing atmosphere, and this is one factor which causes large variations in firing shrinkage. Use of platinum metallization to enable firing in an oxidizing atmosphere was proposed by Keller, Pirigyi, Cole and Budd (1969). This approach had the advantage of burning the binder off easily and keeping variations in firing shrinkage low; however, it has not been used in practice because of the high cost of platinum. Chance (1970) showed that when tungsten metallization was fired the whole substrate was put under a strain by differences in shrinkage, and he investigated the effects of matching shrinkages on the strength of bonding between the metallization and the ceramic. Wilcox (1971) investigated the pros and cons of the selection of a wide variety of ceramic materials and metallization materials, and concluded that alumina and bellyria ceramics, and molybdenum and tungsten metallization were most suitable. He also reported that these materials were more suitable than epoxy-resin printed circuits or thick film wiring substrates for fine wiring, enabling wire widths of 100 μm, through holes 100 μm in diameter, and virtually infinite lamination. This is generally acknowledged at the present time. Finch, Kaiser, Pakulski and Reardon (1970) proposed the concept of continuous manufacture of multilayer wiring substrates (loop conveyor belt process).

Surtani (1971) reported that the air-tightness of Mo/Mn metallization on alumina ceramics was completed by permeation of the metallization layer by a glass matrix formed from the alumina ceramic. Because it is necessary for the metallization in multilayer substrates to be firmly secured when it comes to soldering on the external connecting pins, this research, together with that of Chance mentioned above, includes many indications for future research.

Hargis (1971) suggested that at that time the actual variation in firing shrinkage was $\pm 1\%$, but that it was possible to decrease it to $\pm 0.5\%$ by optimizing the different manufacturing processes. However, they did not make any concrete proposals as to optimum conditions. Shanefield and Mistler (1971) were the first to reveal the doctor-blade method for making thin ceramic sheets (green sheets); the method which they proposed was similar to that used today. They also obtained a variation of $\pm 0.5\%$ in firing shrinkage (not including metallization). Shanefield and Mistler (1974) also reported that for avoiding the agglomeration of powdered ceramics in mixtures with organic solvents it is important to add a deflocculating agent, and that fish oil is suitable for this purpose.

Gardner and Nufer (1984) investigated the mechanical properties of green sheets and clarified the relationships among effective solvent permeability with respect to metallization printing, deformation during lamination, each of punching holes, and binder content.