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1980 INTERNATIONAL MICROELECTRONICS SYMPOSIUM

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Abstracts

IMPROVED TECHNIQUES TO MONITOR THIN FILM CHARACTERISTICS FOR RELIABLE HYBRID MICROCIRCUIT FABRICATION

N. C. Thomas, L. R. Zawicki, *The Bendix Corporation, Kansas City Division, Kansas City, MO.*

Improved testing techniques to monitor thin film product characteristics and process control have been developed at the Kansas City Division of The Bendix Corporation. The techniques were developed primarily to provide a real-time, full-process monitor to test thin film adhesion and to evaluate thin film properties under accelerated aging. Additionally, more cost-effective methods were developed to monitor process control through measurement of film properties that relate directly to key process variables.

A special circuit pattern was designed to offer improved information-gathering capabilities. This pattern is now included on the corner of production substrates to monitor thin film adhesion, via resistance, and resistor film temperature coefficient of resistance (TCR), and life stability.

Minicomputer hardware and software were developed to monitor thin film interface resistance changes under accelerated aging conditions of elevated temperature, high humidity, and corrosive environments.

Curves for different aging characteristics were developed for different thin film metallization systems and for some process and substrate variables. Interface aging characteristics were compared with lead frame bond pull-test data.

PREPARATION AND CHARACTERIZATION OF PATTERNED CHROMIUM/COPPER FILMS DEPOSITED ON ALUMINA

J. P. Cummings and L. S. Weinman, *Honeywell Corporate Technology Center, Bloomington, Minnesota*

Magnetron sputtering formed the basis for processing high resolution chromium/copper grid patterns using a totally subtractive approach or as the adhesion layer for a subsequent semiadditive electroplated metallization. Deposition rates of about 100 nm/min were obtained for sputtered films at power levels of 4Kw over an eight inch target on a rotating table. Electroplated films were deposited at faster (μm/min) rates at room temperature. Typical grid pattern densities of 0.5 – 10 mil lines and spaces are achievable.

Properties of totally sputtered and electroplated films are dependent to some extent on substrate surface topography. The electrical resistivity of thin films increases in proportion to substrate roughness. The resistivity of a 5μm layer of copper on pressed and sintered alumina is nearly twice the bulk value. Near bulk values are obtained on tape cast alumina substrates. Adhesion values for chromium/copper films on alumina have been found to be over 10,000 psi under tensile load. These adhesion values show little degradation as a result of thermal aging at 150° C.

LOW TCR CHIP RESISTORS MADE WITH ENHANCED TANTALUM NITRIDE

K. Park, S. Olster and T. Yasar, *Semi-Films Div. of National Micronetics, Inc., West Hurley, N.Y. 12491*

It is well established that tantalum nitride thin film resistors satisfy all the stringent requirements of hybrid microelectronic circuits where stability and reliability are critical for precision applications.

For reactively sputtered tantalum nitride, there exits the so-called plateau region of deposition which is determined by the amount of nitrogen in the sputtering gas and results in extremely stable resistor films. In this region the film resistivities range from 230 to 400 μ ohm-cm with TCR ranging from –50 to –150 PPM/°C.

Modification of the sputter deposition process results in an enhanced version of tantalum nitride with sheet resistivities up to 120 ohms/square and a TCR of ±10 PPM/° C.

The stability of the enhanced tantalum nitride is found to be equivalent to that of tantalum nitride obtained from the plateau region of reactive sputter deposition. Thin film resistor chips fabricated from the enhanced tantalum nitride show electrical and environmental characteristics that are similar to those of resistor chips fabricated from standard tantalum nitride films.

THIN FILM RESISTOR ARRAYS FOR HYBRIDS

F. M. Collins, *Ohmtek, Inc., Niagara Falls, NY*

A unique tantalum-based thin film having an absolute TCR consistently within 10–20 ppm/°C and inherent self-passivation is utilized for the fabrication of precision miniature chip resistor networks on fine-grained, 10-mil alumina. Tracking of resistors is usually within 1 ppm/°C. Resistance tolerances down to 0.01% are maintained under diverse assembly and environmental conditions. These networks are finding increased use in hybrid circuits where miniaturization, pre-testing, very low TCR, close tracking and exceptional stability are required.

A NEW RC THIN FILM PROCESS USING A SINGLE LAYER OF DOPED TANTALUM

Alain Clei, *PAB/DTS/MOC, Centre National d'Etudes des Télécommunications, 92131 Issy-Les-Moulineaux (FRANCE)*

Sputtering conditions of single tantalum layers giving temperature compensated resistors and capacitors have been studied. Components obtained by this way present electrical characteristics similar to the best tantalum based resistors and capacitors made up to this day. A simplified hybrid circuit fabrication process is described that allows one to reach high sheet resistance by selective anodization of the resistors.

INTEGRATING SURFACE ACOUSTIC WAVE DEVICES AND ELECTRONIC CIRCUITRY INTO HYBRID FORM

P. Romik, *Tadiran, Israel Electronics Industries Ltd., Components Plant, 26 Hashoftim St., Holon, Israel*

The increasing use of Surface Acoustic Wave (SAW) devices in communication and electronic warfare systems enables the achievement of sophisticated signal processing functions. From a technological point of view, SAW devices use construction methods widely popular in hybrid microelectronics. As a result, SAW devices can be easily integrated with outside electronic circuitry into hybrid form.

Several types of hybrid modules incorporating SAW devices have been developed. The modules operate at frequencies of 70 MHz to 200 MHz and include SAW filters, SAW correlators, RF amplifiers, high performance RF switches and digital circuitry.

COPPER-DIELECTRIC INTERACTIONS: A COMPREHENSIVE STUDY

Christian M. Val, Didier Pribat and Dominique Cotto, *Thomson-CSF – Département Circuits Hybrides, B.P. 10 – 91401 Orsay (FRANCE)*

At Thomson-CSF, studies have been performed on non noble thick film materials for more than three years. Blistering and shorting have been investigated in some details, as longstanding problems, having delayed the development and use of thick film multilayer structures.

The very first purpose of this work was to understand mechanisms of blister formation. Hypothesis were also formulated allowing an explanation of shorting phenomenon.

Blistering is believed to rely on chemical interactions between the copper, the dielectric and the atmosphere. Thus a complete understanding of the chemical composition of inks under study was first necessary. Analyses were performed on Du Pont, Cermalloy, Plessey and LEP materials.

Most common crystalline phases found in commercial dielectric compositions are $MgAl_2O_4$ (Spinel), Al_2O_3, ZrO_2 and ZnO before firing. Changes were noticed after firing Du Pont and LEP materials which incorporate a devitrifying glass in their composition. This leads respectively to Hyalophane and Zn_2SiO_4 formation.

Thermal stability of crystalline dielectric phases was checked using a computer program. Results evidenced Zn_2SiO_4 decomposition. The kinetics of organic binders decomposition during firing were also studied by thermogravimetric analysis, using different atmosphere compositions. Results indicate weight loss differences on the different dielectric materials when heat treated under pure nitrogen or air. However, the mechanisms of resin elimination are distinct, depending on dielectric composition.

Moreover, using Electron Micro Probe Analysis, copper was evidenced within the dielectric layers and Auger Electron Spectroscopy allowed precise analysis of the inside walls of a blister.

Knowing all the results, thermal decomposition of some crystalline phases along with slow oxidation of entrapped carbon residues were judged to be responsible for blister formation, and these mechanisms are discussed in some details in the paper.

BLISTERING IN Cu THICK FILMS: HOT STAGE MICROSCOPE STUDIES

D. Pitkanen, J. Cummings and J. Sartell, *Honeywell Corporate Material Sciences Center, Bloomington, Minnesota*

Thick film hybrid circuits have found wide application in electronic packaging technology for a number of reasons, among which are cost and reliability. These circuits are generally made with precious metal conductors, most commonly gold, platinum-gold or silver-palladium alloys. Rapid price escalation of precious metals has led to a search for more economical materials systems based on copper, aluminum or tungsten conductors.

Copper thick film systems have been under development at Honeywell for some time and recent progress has made these systems most promising. Although considerable progress has been made in understanding and controlling the factors which affect compatibility (e.g., interdiffusion of Cu and dielectrics), blistering has been a recurrent problem. This investigation was aimed at identifying the underlying causes of blistering in copper thick films in order to provide effective means of control.

Earlier research had suggested that the occurrence of blistering might be related to the oxide content of the Cu paste, and that decomposition of the oxides during firing might cause the evolution of gases. A series of experiments using a hot stage microscope was designed to test these ideas and to provide a better understanding of the blister formation process.

Test circuits were screened using DuPont 9923 copper printed on several commercial paste dielectrics including ESL 4901, DuPont 4175 and DuPont 9949. These were dried at 150°C for various lengths of time to provide different amounts of oxidation of the copper powder. Subsequent firing was done both in a conventional manner using a nitrogen atmosphere in a conveyer thick film oven and in a hot-stage microscope using a nitrogen atmosphere. Infrared spectroscopy was used to analyze the effluent gases resulting from vehicle burnout. This provided a better picture of the chemical processes involved.

These experiments have provided spectrographic evidence that pyrolysis is involved in vehicle burnout, rather than evaporation alone. The products of pyrolysis such as carbon and vehicle fragments provide the chemicals which can react with metal oxides to form gases such as CO or CO_2. In addition, the hot-stage microscope permitted real-time microscopic observation of the occurrence of blisters, measurement of the temperature of blister appearance and disclosed a geometric relationship for the formation and the location of blisters.

The findings show that blistering is a function of substrate, copper paste composition or dielectric paste composition, oxide content of the conductor paste and temperature. Furthermore, pyrolysis of the vehicle and reaction of the oxides with the products of pyrolysis or with vehicle components enters into the chemical processes involved in blistering. Based on these results, recommendations are made for the control or elimination of blisters through material and process modifications.

BASE METAL THICK FILM CONDUCTORS

S. J. Stein, C. Huang and L. Cang, *Electro-Science Laboratories, Inc., Pennsauken, N.J. 08110*

This paper discusses base metal conductive thick films formed by firing in air. The metals under study include nickel, chromium, aluminum and copper. The properties of the films are presented for firing temperatures ranging from 580 to 850 degrees C. Compatibility with various dielectrics and glasses have been studied. Specialized multilayer uses seem feasible. Potential uses on porcelain enameled steel, window glass and alumina substrates are reviewed and data is supplied. Difficulties in bonding, joining and contacting these materials are described.

Initial studies have been made of compatibility with thick film ruthenium-based resistors. Some data on termination resistance problems and other properties observed in combinations of base and precious metals are presented.

Possible applications in gas discharge displays for cathodes and conductor runs are discussed. Potential uses may include ground planes, solar cell electrodes and varistor, thermistor and other passive device terminations.

A COPPER COMPATIBLE LOW K DIELECTRIC FOR MULTILAYER APPLICATION

H. Baudry and M. Monneraye, *Laboratoires d'Electronique et de Physique Appliquée 3, avenue Descartes, 94450 Limeil-Brévannes (FRANCE)*

This paper describes a low K dielectric to be used as in insulating layer, compatible with copper thick film conductors, for multilayer applications. Keeping in mind the fact that firing has to be performed in industrial nitrogen, a paste formulation is discussed, which leads to satisfactory results both from the geometrical, mechanical and electrical points of view. The same firing atmosphere (typically 5 to 10 ppm oxygen) is used both for copper conductors and the dielectric.

ADVANCES IN THICK FILM ALUMINIUM CONDUCTOR PROCESSING

R. E. Cooper, P. F. T. Linford and J. Savage, *Microcircuit Technology Group, Metallurgy Division, AWRE, Aldermaston, Berks., UK*

Aluminium thick film conductors offer very large cost advantages compared with noble metals and may also improve the reliability of circuits by eliminating gold-aluminium interfaces and their attendant inter-metallic phenomena. Until recently however, it has not been possible to produce aluminium thick film conductors which are ultrasonically bondable to aluminium-silicon wire. Recent work by the authors has revealed the microstructural changes which occur on firing a commercially available thick film aluminium paste with various schedules and has suggested revised schedules which yield conductors with useful ultrasonic bondability and conductivity. Ageing experiments on bond strength and conductivity have also been carried out. The present paper summarizes this work and describes additional work which has been carried out on ageing and on bond yield as a function of bonding tool design. The latter work has led to an improved combination of bond yield and line conductivity. It is concluded that an all-aluminium interconnection technology is feasible possibly using a double print and fire technique to give interconnect lines of good conductivity and bonding pads of good bondability.

AN ANALYSIS AND COMPARISON OF MICROCIRCUIT PERFORMANCE USING AN AIR FIREABLE NICKEL CONDUCTOR AGAINST TYPICAL LOW-COST PRECIOUS METAL FORMULATIONS

Robert W. Friedhofer, *Weston Components & Controls, Archbald, PA.*

The recent upsurge in precious metal costs has forced developmental and manufacturing engineering groups to seek cost effective substitutes for traditional precious metal conductors. The purpose of this paper is to present the observed performance trade-offs required by the use of base metal conductors.

This study compares the performance of various commercially available resistor and conductor systems when used in conjunction with an air fireable nickel termination. As with most base metal conductors, an interface is required between the resistor and the base metal conductor. A portion of this study has been dedicated to the design criteria of the interface, and any effects geometry or size variation of the interface has on resistor performance.

LOW COST LARGE SUBSTRATES FOR MICROWAVE INTEGRATED CIRCUITS

Michael D. Kline and Theodore M. Nelson, *Westinghouse Electric Corporation, Command and Control Division, Baltimore, Md. 21203*

Alumina substrates have long been used in Microwave Integrated Circuits (MIC's) fabrication because of their excellent electrical characteristics. The new generation of large MIC's are now requiring substrate sizes of up to 6″ x 18″; however, alumina substrates can only be used effectively in 2″ x 2″ sizes because of their brittleness and difficulty in machining.

Now available in sizes up to 9″ x 12″ are soft substrate materials with dielectric constants similar to alumina. One piece of such a material can replace several alumina substrates in MIC's. This paper describes the use of 3M Company's Epsilam 10 and Rogers Corporation 6010 soft substrates in such circuitry. Test results such as microwave insertion loss, tuning evaluation, solder adhesion, effects of humidity on loss and dielectric constant and the use on state-of-the-art production L-Band hybrid modules are compared for the two materials. A comparison with alumina is also made when applicable. It is shown that in high power L-Band solid state amplifier modules, at least one of the soft substrate materials can be used as a direct replacement for alumina.

PORCELAINIZED STEEL SUBSTRATE TECHNOLOGY: STATE-OF-THE-ART CONSIDERATIONS IN ITS APPLICATION

Philip A. Lindner, *General Electric Company, Solid State Applications Operation, Syracuse, New York*

Dr. David Green, *General Electric Company, Photo Lamp Engineering, Cleveland, Ohio*

The Porcelainized Steel Substrate (PSS) technology is attracting considerable attention after playing a background role in hybrid circuit technology for a number of years. This role has been primarily in the areas of printed wire

boards with little use of printed passive elements. Within the last few years, however, cost and packaging considerations have prompted interest in expanding the use of porcelainized steel as a substrate for conventional thick film hybrid circuits. PSS technology is unique in that it can serve as an alternative for both small scale thick film hybrids on ceramic substrates and for conventional large area printed circuit boards. This is not to say that PSS technology is about to overwhelm these two established technologies. Indeed, even after this technology has progressed down the learning curve to a point of proven and consistent performance, it is likely that there will remain significant areas where PSS cannot match ceramic substrates or printed circuit boards in cost and/or performance. A more likely eventuality might be PSS technology functioning in a complementary (rather than competitive) mode much the way that thick film resistor networks complement and enhance (rather than compete with) printed circuit board technology.

Regardless of whether PSS technology is going to replace or complement current technologies or be used in a novel application, it is of utmost importance to realistically assess the state-of-the-art (i.e., current capabilities as well as position on the learning curve). It is this paper's purpose to serve this function especially in regard to PSS for thick film hybrids.

In the area of hybrid circuit technology, the major differences between PSS technology and the conventional alumina substrate technology lie in the "product maturity" of available thick film pastes and in the passivity of the substrate material (i.e., the extent to which the substrate interacts with or influences printed films). This paper outlines techniques for quantifying these and other factors as well as presenting specific data comparing capabilities of three suppliers' (DuPont, ESL and EMCA) PSS compatible pastes with established alumina compatible materials. Emphasis is placed on the impact of any differences on circuit layout and fabrication.

PRELIMINARY INVESTIGATION OF POTENTIAL BERYLLIUM EXPOSURE WHILE LASER TRIMMING RESISTORS ON BERYLLIA SUBSTRATES

E. Foley and G. Rees, *Brush Wellman Inc., Elmore, Ohio 43416*

With the ever increasing use of beryllia substrates in the electronics industry, and laser trimming of resistors on these substrates, the question of potential exposure to beryllium must be examined. Beryllium, when inhaled, has the potential to cause adverse health effects if exposure concentration is excessive.

This paper reports the results of a preliminary air sampling survey in the work area of an Electro Scientific Industries Model 25, YAG laser while trimming thick film resistors on beryllia. Substrates trimmed during this survey were one inch square 99.5% BeO and printed with DuPont thick film resistive materials. Numerous air samples were taken in varying proximities to the trimming site, some as close as four inches from the beam impaction point. Additional samples were taken of general air conditions and the operator's breathing zone area. The laser operator wore a personal type lapel sampler during all trimming operations. Air samples were taken during the trimming of 599 substrates. This is the equivalent of several thousand substrates when the test procedure is considered. Of all samples taken, only two showed any detectable beryllium and both of these are well below the allowable limit.

SCREEN PRINTED CONDUCTORS AND RESISTORS ON ALTERNATIVE SUBSTRATES TO ALUMINA

Martin V. Coleman, *Standard Telecommunication Laboratories Limited, Harlow, Essex, England*

A comparative evaluation has been made of the materials available for printing on to porcelainised steel, soda lime glass and phenolic resin board. Inherent conductor adhesion strengths were found to be as good as many conductors on alumina although care had to be taken to avoid solder leaching. By the use of protective overglaze lacquers, silver migration could be prevented even under severe humidity conditions. The interaction between conductor and porcelainised steel enamel was excessive and a peak firing temperature below 650°C was preferred. Resistor performance was generally satisfactory although improvements needed to be made on the higher resistivity inks on glass. Resistors on phenolic board performed well except when subjected to temperatures in excess of 150°C which caused a reversible breakdown in the conducting paths between carbon flakes within the resistor.

TRENDS IN INTERCONNECT TECHNOLOGY

James D. Welterlen, *Technical Consultant, La Jolla, California*

The new generations of solid state devices have changed the complexity, speed and power considerations for interconnecting them. Present and future trends in first and second level interconnections will be discussed. Competing technologies including thick film, thin film, cofired multilayer, porcelain on steel, polyimide and conventional

printed circuit boards (PCB) will be compared for circuit density, thermal and electrical performance, design flexibility and cost.

The use of tape automated bonding (TAB) and chip carriers as means of pre-packaging the integrated circuit devices and the impact on these interconnection systems will be reviewed. The effect of automatic placement equipment will also be considered.

Capabilities required in the future and some possible directions for new technology will be presented.

"MO PACKAGING" – A NOVEL METHOD OF MULTICHIP PACKAGING

T. Nukii, M. Iwasaki, Y. Matsuda, H. Yoshida, S. Nakabu and K. Awane, *Central Research Laboratories, Sharp Corporation, Ichinomoto, Tenri, Nara, JAPAN*

The advent of highly functional and complicated electronic equipments calls for a multiplicity of functions to be incorporated in a single IC package, hence a strong demand for high density packaging ensues. To meet this demand, a new multichip packaging method, which we call the "MO Packaging" (*M*etal based *O*rganic film Packaging), has been developed.

This packaging method allows building of high density package of a thin configuration, characterized by an effective combination of a metal plate, organic films, tape carrier devices, and bumped electrodes made on the substrate. The MO Package compares favorably with conventional packages in heat dissipation and insulating characteristics. It also has other remarkable features such as the possibility of utilizing the wired metallic packaging substrate as a casing of the electronics by making the most of the substrate's press-forming capability. This is considered to be an epoch-making packaging technology which will be applied in a variety of fields.

This paper deals with the proof and demonstrations of these features by describing the process of packaging. It also touches upon the future prospects of the technology.

AUTOMATIC HYBRID TESTING

William W. Wareham, *Hewlett-Packard, Civil Engineering Division, Loveland, Colorado*

Hybrid microcircuit testing is becoming an increasingly important problem as these devises proliferate in today's smaller and more complex products. One decision that must be made by the manufacturer who produces intermediate quantities per year is whether to buy an automatic test system or to build a manual test station using discrete test gear. The initial reaction is usually to throw together a manual system because it is faster and cheaper. Having had experience with both types of systems, we find that this approach is short sighted.

Viewing hybrid testing as basically the same as PC board testing except for fixturing opens the potential for using one of the automatic PC board test systems now on the market as a hybrid test system. Fixturing is primarily a mechanical design problem with any number of solutions, the correct one being determined by the particulars of a specific application. We have successfully used an HP 3060A Board Test System to test a variety of hybrid microcircuits in a production environment. Here we describe a number of factors that must be considered when choosing between automatic and manual test systems and some of the results of having chosen the automatic route. Some of these results were direct and measurable while others, though equally important, were less tangible. We also describe some potential fringe benefits of automatic testing which may, in the long run, be reason enough to use an automatic approach.

SOLID PHASE SOLDER BONDING FOR USE IN THE ASSEMBLY OF MICRO-ELECTRONIC CIRCUITS

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A Solid Phase Solder Bonding technique has been developed and used to attach spherical solder preforms in a single array to hermetically sealed chip carrier package terminations. The process output can be about 300 packages per hour for the single array format, but can be increased to about 1800 per hour for a multiple array. Four types of solder (10%Sn–90%Pb, 96%Sn–4%Ag, 60%Sn–40%Pb, and 95%Pb–5%Sn) have been Solid Phase Bonded to both thick (PtPdAg, PdAg) and thin (TiPdAu, TiPdCuNiAu) film metallizations. The process can be used to provide component standoffs that ensure consistent height between a component and the circuit FIC or PWB to allow flux removal and subsequent encapsulation beneath the component.

This paper describes the Solid Phase Solder Bonding process and typical applications.

FURNACE FIRING ATMOSPHERES

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Most thick film processors are aware of the need for a relatively clean and consistent supply of air for their furnace firing atmospheres. Many have met the need by carefully selecting the location of intakes for their air supplies and by the installation of quality air drying and oil removal equipment. The assumption is made that a clean air supply insures a clean firing atmosphere; however, there is in addition to this a quantity of room air, of questionable quality, which enters a furnace and combines with the supply air to produce the actual firing atmosphere.

In this paper it will be demonstrated that 1) furnace atmospheres are comprised of a mixture of room air and air line air; 2) in most modern furnaces it is possible to effectively eliminate room air in the furnace by adjusting flow volumes in various portions of the furnace; and 3) consistent quality and reproducible resistor values will result from firing in clean, consistent furnace atmospheres that exclude room air.

DEVELOPMENT OF ALUMINIUM BALL/WEDGE WIRE WELDING

Keith I. Johnson, Michael H. Scott, Christopher J. Dawes, *The Welding Institute, Cambridge, England*

Interconnections between active circuit chips and external circuitry are generally made by ultrasonic wedge/wedge bonding of 25μm diameter Al wires or by ultrasonic or thermocompression ball/wedge bonding of 25μm diameter Au wires. The latter technique has a number of advantages, especially when the process is automated, but its restriction to Au wire gives economic and reliability problems. These problems have been eliminated by the development of ball/wedge Al wire bonding. This has been accomplished during the last four years by: developing and designing ball forming techniques suitable for commercial manual wire bonding machines; optimising balling procedures and bonding conditions when attaching 25μm diameter Al wires to various commonly used substrates; and establishing the reliability of such Al ball bonds under environmental test conditions.

Equipment employing an electric arc and an inert gas shield has been developed for forming balls on Al wire. This equipment is easily incorporated onto standard ultrasonic Au wire ball/wedge welding machines. Ball and capillary wedge bonds of good strength were made with 25μm diameter Al-1%Si wire to Al thin films, Pd-Ag thick films and Au flashed Kovar. The capillary wedge bond is considerably improved by using a specially designed flat faced capillary.

"Cerdip" packages have been subjected to dry heat (250°C, up to 1000 hrs) and temperature cycle (–65° to +200°C, up to 1000 cycles) and assessed by electrical and mechanical testing. Although reductions in bond shear strength and changes in bond voltage drop were observed during these tests, these changes were small and unlikely to have any practical significance.

COMPONENTS FOR MEDICAL ELECTRONICS

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The problems of buying components for medical electronics is examined. It is necessary on the one hand to buy the best parts available, whilst on the other hand be realistic about the cost. Component specification are considered in terms of packaging and hermeticity, attachability and bondability, and electrical performance.

USING HYBRIDIZATION AS A VIABLE SPACE-SAVING TECHNIQUE IN A MYOELECTRIC ARTIFICIAL ARM

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This paper is not a discussion of the hybridization process itself, but its application in solving the unique problem of miniaturizing the electronic circuitry in a myoelectric artificial arm. At the present time three of the eight hybrid circuits required have been built, with the remaining circuits constructed by hand. Details of the requirements are presented.

HYBRID PACKAGING FOR CARDIAC PACEMAKERS

Craig C. Tschohl and Sid Bhatt, *Cardiac Pacemakers, Inc., Arden Hills, MN.*

Packaging of electronic circuits for implantable medical device applications has evolved from cordwood and discrete device/printed circuit board configurations to a variety of hybrid circuit configurations. The most widely used configuration has been the all metal rectangular package.

As performance requirements for pacemakers changed requiring smaller size, lighter weight, physiological shape, and more functions the packaging of the circuit has had to be modified to comply. Domed covers replaced stepped lids; rectangular shape changed to five sided and eventually to a package that conformed exactly to the outer pacemaker shell. In order to comply with electrical requirements, package material has changed from a commonly used magnetic material to a non-magnetic one.

This paper discusses the approaches taken in meeting these packaging challenges, the associated problems encountered, and process techniques and materials used to successfully process these unique package configurations.

A SECOND GENERATION INTRACRANIAL PRESSURE MONITORING SYSTEM

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A micropower pulse frequency/pulse code modulation (PFM/PCM) telemetry transmitter has been designed for measuring intracranial pressure (ICP) and temperature. The PCM scheme used in the pressure channel achieves an accuracy of 0.2% F.S. Pulse powering technique reduces the current consumption to about 50 μA from a 5.6 V power supply at a 100 Hz sampling rate. At a 20 Hz sampling rate, the current consumption is further reduced to about 10 μA.

The telemetry transmitter is implemented using two semi-custom integrated circuits along with a commercially available CMOS A to D converter. Fabricated on a 0.8" x 0.75" hybrid substrate, all the electronics are housed inside a 1" x 1" hermetically sealed Kovar flatpack along with the pressure transducer. Powered by two lithium batteries measuring 16 mm in diameter and 2 mm in height, the transmitter has a continuous operation period of 1000 hours.

AN IMPLANTABLE MICROPOWER COMMAND RECEIVER FOR TELEMETRY POWER SWITCHING

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Hybrid command receivers that detect pulsed RF instructions and control the functioning of additional circuitry can be useful in many medical telemetry applications. We have designed and constructed a thick-film hybrid command receiver system that directly interfaces with the second generation ICP telemetry transmitter.

This paper details the features of this hybrid command receiver and its ability to control the implant ON/OFF state. Other more complex command receiver designs currently being investigated will also be discussed.

EVALUATION OF INTERPOSED GOLD WIRE LEADS FOR TC BONDED EXTERNAL HIC CONNECTIONS

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Described in this paper is an evaluation of interposed (IP) gold wire leads for thermocompression (TC) bonding of external connections to thin film Hybrid Integrated Circuits (HIC's). IP gold wire attached to the lead bonding area provides several important advantages over TC bonding with gold-plated copper leads. The IP gold wire provides compliancy. This reduces substrate damage during bonding and increases initial yield. The compliant gold, instead of the lead, provides the required deformation to achieve strong TC bonds. This permits use of stiffer lead materials, which maintain more accurate lead alignment for socket and PWB insertion.

This evaluation of IP gold wire TC bonding to HIC thin films consisted of (a) optimizing bonding temperature and pressure, (b) shelf aging of leads, and (c) accelerated temperature aging and temperature cycling of IP wire bonds. Results of these evaluations are reported for CDA-110, CDA-155, and CDA-195 lead materials.

Results show that IP gold wire bonds are significantly stronger than conventional TC bonds. An Arrhenius analysis of the aging data predicts that the IP wire bond life exceeds 40 years at 90° C. This compares favorably with TC bond lifetimes exceeding 40 years at 50° C for leads plated with thin gold.

THE AGEING BEHAVIOUR OF COMMERCIAL THICK- FILM RESISTORS

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An earlier paper reported the promising prospects of accelerating thick-film resistor ageing by elevated temperature and humidity stress; those early findings have now been confirmed by further results from many thousands of hours of overstress testing of commercially-produced resistors from various sources – amounting to accumulated test times of some millions of resistor-hours. The normal aging trend is a steady increase in resistance at a rate influenced by various factors such as manufacturing origin, resistivity, electrical bias, environment and encapsulation. The majority of the increases vary with the square-root of time, consistent with a diffusion-controlled degradation of the conduction processes. Some changes also conform to piezo-resistive effects and together these provide physical explanations for the ageing behaviour of thick-film resistors. The drift observed in the majority of resistors can be extrapolated to give a prediction of less than 0.5% change in 20 years operation in standard environments – a heartening prospect indeed for thick-film reliability.

THE REWORK OF HYBRID MICROELECTRONICS

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Until recently, Hybrid Microelectronic rework has been a subject that has not been openly and freely discussed among manufacturers and users. Users and manufacturers of Hybrid Microelectronics have realized that rework is a "fact of life", so much so, that the overall yields which influence the selling price of the finished product, are affected by the manufacturer's ability to do successful rework. As with costly complex hybrids, and with the advent of the Large Scale Hybrid (LSH), the ability to successfully rework or repair presealed sealed and field returned hybrids is essential. The need for rework is further highlighted when lead time has reached 50 weeks for some hybrid material.

This paper combines a number of studies conducted under the auspices of the JEDEC JC13.3 Committee, Task Group 20 and the author's experiences. It contains the background of hybrid rework, the view and latitude taken by both manufacturers and users, the current military specification approach, a recommendation for military specification revision, and the planned updated military approach.

SURFACE ANALYSIS FOR FAILURE DIAGNOSIS IN MICROELECTRONICS

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Sophisticated techniques of surface analysis have been refined to the point where they are in regular use for QA/QC, research, development, characterization, and failure analysis of microelectronic devices. The most commonly used techniques are Scanning Electron Microscopy (SEM), Electron Spectroscopy for Chemical Analysis (ESCA), Secondary Ion Mass Spectroscopy (SIMS), and Scanning Auger Microanalysis (SAM). Each has advantages for particular applications. SEM provides images of the surface topology with unexcelled lateral resolution. ESCA adds information about chemical bonding, but loses most of the spatial resolution. SIMS has the highest sensitivity, but also presents the greatest difficulty in interpretation.

Recent experience in our laboratories has identified SAM as the most broadly useful of these techniques. Its advantages include sensitivity to a shallow (typically 2–10nm) surface layer, imaging with good spatial resolution, profiling capability, relative constancy of the sensitivity in various matrices, and the resulting ability to do semi-quantitative work with a minimum of computational complexity. The combination of sensitivity to a shallow surface layer and good spatial resolution makes possible an analyzed volume of the order of 10^{-16} cm^3.

The wide range of studies using SAM cannot be covered comprehensively, but many of the problems encountered can be classified as 1) bonding/adhesion, 2) irregularities in layered systems, and 3) surface contamination. We have encountered bondability problems due to the presence of solder flux residues, carbon contamination, oxidation, and migration of constituents. Problems with layered systems have been diagnosed as due to delamination at particular levels, contamination in or between specified layers, and interdiffusion or improper thickness or constitution of layers. Surface contamination from numerous sources including photoresist residue, contaminated deposition chambers, and incomplete wash/rinse after some steps of the manufacturing process can produce a wide range of undesired effects.

A QUALITATIVE STUDY OF THICK FILM POWER RESISTOR FAILURE UNDER OVERLOAD CONDITIONS

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Thick film hybrid circuits and thick film resistor circuits are used throughout the electronic switching systems made by GTE Automatic Electric. They are used in some applications where accidental power overload conditions can occur due to lightening surge and power cross on the line. These overloads may result in a predictable failure mode which is caused by the high thermal stress put on the thick film circuit. It is this stress condition which was studied to define its effects on thick film power resistors developed for use in such a harsh electrical environment.

FABRICATION OF MILLIMETRE WAVE INTEGRATED CIRCUITS BY THICK FILM TECHNIQUES

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Circuits for use at frequencies above about 30 GHz are difficult to produce with conventional waveguide, microstrip or stripline components. The circuits are either very expensive to produce to the required dimensional tolerances or the line loss becomes unacceptably high. This has led to a search for alternative millimetre wave technologies and one promising alternative is based on the use of strips of dielectric material mounted on a reflecting ground plane to guide the waves. The guides typically have a rectangular cross-sectional shape, and, at a frequency of 60 GHz using a dielectric with a permittivity of 10, for example, the width of guide is about 1.2mm and the thickness 0.6mm. The modes of propagation are such that the field is not tightly confined within the guide and hence dimensional tolerances needed are much wider than for an equivalent metallic waveguide. Using low loss alumina ceramic acceptably low line loss has been achieved. Unfortunately the fabrication of discrete pieces of ceramic of the requred shapes and with the flatness necessary to achieve intimate contact with the ground plane is difficult and moreover has to be followed by a rather intricate assembly operation.

The paper describes the successful fabrication of dielectric guide circuits for use at frequencies of 60 GHz and above in situ on a ground plane by techniques analagous to those used to produce screened and fired thick film circuits. This has involved the development of low loss thick film dielectric material, producing printed layers up to about 1mm in thickness, and devising drying and firing schedules capable of yielding dense fired lines of the required shape, thickness, and regular cross-section. Line losses of better than 0.1dB/λ have been achieved. A variety of circuit elements such as couplers, attenuators and mixers has been fabricated in dielectric guide form and the technology is well suited to the direct attachment of unpackaged semiconductor devices. It is concluded that this new extension of thick film technology has great potential for the fabrication of low cost millimetre wave circuitry.

THE DEVELOPMENT OF 8″-100 lpi THICK FILM THERMAL PRINTHEADS

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This paper describes a development program undertaken in our laboratories for the fabrication of prototype 8″-100 lpi thick film thermal printheads. The printhead consisted of a 9″ x 3″ alumina substrate with 800 resistor elements terminated by conductor lines which in certain areas have a maximum resolution of 3 mil widths and 2 mil gaps. It is shown that these features require careful choice of thick film material, optimization of all printing and firing processes and the use of cleaner and better controlled thick film facilities than is typical of a hybrid manufacturing environment. The fabrication procedure is described and problems encountered are discussed. The high quality print of the prototype thermal printhead is demonstrated and future developments are outlined.

MINIMIZATION OF CROSS-TALK BETWEEN RC ACTIVE FILTERS ON A SINGLE CERAMIC SUBSTRATE

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This paper describes thin film RC active filters which can provide minimum cross-talk between them on a single small ceramic substrate. The realized cross-talk was less than −60 dB in gain between 10 Hz and 10kHz.

The filters fabricated on the substrate were a pair of transmitting and receiving filters for use in pulse-code

modulation (PCM) systems and they were developed by using tantalum film technology. The configuration of the filters was a twenty-four pin dual in-line package with the substrate dimensions of 0.82mm thick, 30mm long, and 10mm wide.

The minimization of the cross-talks have been carried out by arranging the grounded conductor film between the two filters together with back metallization to the substrate. Employment of the conductor film between the filters alone or the back metallization alone was not so effective in reducing the cross-talk.

The thin film RC networks for the filters were fabricated through the process referred to as the "RC short process". They were assembled by using wire-bonded SIC's with flowcoated LTV silicone rubber.

NEW THICK FILM RESISTORS FOR POTENTIOMETER APPLICATIONS

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Thick film resistive elements have gained wide acceptance in trimmer and precision potentiometers both as discrete components and as parts of more complex circuits. The thick film approach provides advantages over wire wound elements in stepless resistance resolution, range of available resistance values, adaptability to miniaturization and low manufacturing costs. However, some performance deficiencies of available systems still exist, in particular, excessive contact resistance variation and unacceptable changes in resistance when devices are subjected to repeated cycles of the movable contact. Also, improvements in process sensitivity, environmental stability, and printability are needed.

This paper describes a new series of blendable resistor compositions from 1.5Ω/□ to 10^6 Ω/□ developed to overcome these deficiencies. Temperature coefficients of resistance for the new compositions are within 50 ppm/°C over the 10^2 to 10^6 Ω/□ range and less than 150 ppm/°C for the lower resistivity grades. Particular emphasis is given to new glass chemistries which provide smooth abrasion resistant composites to minimize wiper wear. Resistor performance in potentiometer related tests and under various environmental conditions are also detailed. Resistance changes of 1% or less were observed on all compositions when subjected to a standard 200 cycle test using nickel/ silver wipers in a configuration simulating actual potentiometers. Under the same conditions contact resistance variation was consistently less than 0.5%. Resistor stability after prolonged aging under various environmental conditions demonstrates a considerable improvement over current technology for those compositions covering the 1.5 to 10Ω/□ resistivity range. Higher resistivity grades showed no measurable changes after 1000 hours at either room temperature, 40°C/90% RH, or 150°C.

The improvements in potentiometer performance are related to surface characteristics using supportive scanning electronic photomicrographs. Performance comparisons are made to other thick film resistor systems.

A PRACTICAL UTILIZATION OF THE PIEZORESISTIVE EFFECT IN THICK FILM RESISTORS: A LOW COST PRESSURE SENSOR

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A new type of pressure sensor has been developed by taking advantage of the piezoresistive effect in thick film resistors screened-and-fired on ceramic diaphragms. The device looks able to satisfy the requirements for low cost, high performances and high reliability. In this paper the physics of the piezoresistive effect in thick film resistors is discussed and the technological approach to and performances of the pressure sensor are described.

CHARACTERIZATION OF A NEW DRY FILM POSITIVE ACTING PHOTORESIST FOR FABRICATION OF HIGH DENSITY LINES IN ELECTRONIC PACKAGES

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John P. Vikesland, *3M, Printing Products Division, St. Paul, Minnesota*

High density line requirements of electronic packages of the future render screen printing technology inadequate. A photolighographic process used in combination with thin film and electroplating technologies has been examined. A description is presented of the lamination and process steps of a new dry film resist by 3M and its comparative behavior when applied to ceramic substrates.

The resist uses a specifically designed laminator with precision preheat controls. After lamination and removal of

backing film, subsequent processing steps are similar to those of a positive liquid photoresist. The properties investigated include the resolution limits of the resist, its compatibility with alkaline gold and acidic copper electroplating baths, and process simplicity. The parameters evaluated have been compared with one of each type of resist, namely a positive acting wet film, a negative acting wet film, and a negative acting dry film resist.

Examination of the resist patterns involve both optical and scanning electron microscopy. System resolution is defined and quantitative measurements are graphically displayed to show effects of projected image definition of photomask, exposure time, mask line width, substrate surface topography and type of resist. These studies have shown that 3M positive acting dry film resist could successfully meet stringent electronic packaging requirements, both technically and from a production point of view.

BTAB – THE ELUSIVE SUCCESS

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Successful utilization of the BTAB (Bumped Tape Automated Bonding) technology has been elusive. Early successes promised quick results with this new approach to microinterconnection. The reality has been slow, steady progress and understanding – a form of technical growth that is really quite typical.

A recent variant of tape carrier hybrid microcircuit assembly, BTAB, utilizes bonding projections formed integrally on the tape carrier rather than on specially processed 'bumped' ICs. Such tape carriers, in both electrically testable and non-testable forms, have been commercially available for some time from various sources.

This paper deals with the general case of BTAB tape carriers bonded to standard commercially available aluminum-metallized ICs and discusses the inconsistent results reported by various workers. Such inconsistencies are most probably due to very subtle and previously overlooked anomalies in the tape carriers, bonding equipment, and bonding processes used. The results of an extensive experimental program utilizing different types of BTAB carrier tape and various types of ICs are described. A detailed analysis correlating the effects of tape defects on IC bonding results is presented. The characteristics of presently available bonding equipment are discussed and recommendations for successful bonding of BTAB tape onto standard aluminum-metallized ICs are given. The basis for an optimistic prognosis for this technology is described in detail.

HYBRID MICROELECTRONICS IN MODERN CAR RADIOS

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Car radio customers of today demand an increasing number of electronic and mechanical functions in a small box whose volume is becoming smaller and smaller due to decreasing available space in and behind the dashboards of future cars.

In this paper ways are described of how this space problem can be overcome by replacing conventionally built-up circuitry with modern thickfilm hybrid circuits wherever it is feasible from an electrical and economic point of view. Hybrid circuits can be assembled in different technological ways, both chip and wire and soldering techniques. General rules for optimal application of these different technologies will be discussed.

There is a big impact of thickfilm hybrid application on reliability and flexibility of electronic circuits which will be proved by examples.

Problems of hybrid circuit application will be mentioned too. These problems specially arise from device cost and availability as well as testability of chip components.

A short presentation of an almost fully automatized thickfilm manufacturing area will conclude the paper.

DYNAMIC CHARACTERIZATION OF AN AUTOMATIC THERMOSONIC WIRE BONDER

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During the development of a hybrid assembly utilizing dual metalization chips, a bonding problem was encountered with an automatic thermosonic ball bonder. The problem was cratering of the silox underneath the bonding pads resulting in lifted pads.

This did not occur when these same devices were bonded on a manual thermosonic bonder using the same machine settings of bond pressure, stage temperature and power level. Since the success of the project depended upon the ability to automatically bond these devices, it became necessary to determine the differences in the dynamic bonding characteristics of the two machines.

In order to do this, a miniaturized strain gauge was developed that permitted the viewing of the actual force

profile of the bonding cycle. The strain gauge is mounted directly onto the bonding stage and is deflected by the bonding capillary when a bond is made. The output of the strain gauge is fed through an amplifier to a storage oscilloscope, allowing one to see the effects of varying the principal parameters affecting bonding in real time. These include search height, bonding time, bonding pressure, power setting and machine cycle time.

Through the use of this strain gauge technique, the differences in the dynamic characteristics of the automatic bonder and the manual bonder were determined. The automatic bonder was modified so that it now closely duplicates the manual bonder and the cratering problem has been eliminated. This solution enabled other minor problems to be seen which will also be discussed.

DESIGN CONSIDERATIONS FOR HIGH SPEED DIGITAL HYBRIDS

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State-of-the-art military electronic applications are demanding increasingly higher digital processing speeds for greater information-handling capability. This requirement is often coupled with tighter packaging constraints, thereby eliminating the use of conventional PCB's and discrete components.

This technological challenge can be met by the hybridization of high-speed logic families such as ECL and CML. The utilization of these logic families in a hybrid configuration necessitates additional design considerations over and above conventional hybrid design practices. The smaller geometries inherent in hybrids mandate that the hybrid design engineer now takes into greater consideration parameters such as cross-talk, capacitive loading, characteristic line impedence, line termination, power dissipation, supply bypassing, etc.

This paper discusses the authors' experimental findings and theoretical calculations for these parameters and presents a set of design considerations for use in high speed digital hybrid design.

INDIUM TIN OXIDE/SILICON SOLAR CELLS ON POLYCRYSTALLINE SUBSTRATES FABRICATED BY NEUTRALIZED ION BEAM SPUTTERING

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Indium tin oxide (ITO)/silicon solar cells of practical size (~ 4 cm^2) and efficiency (> 11% total area) have been fabricated using an optimized ion beam milling/sputter deposition and low pressure oxide growth process. Results for a single crystal silicon substrate and four potentially low cost polycrystalline substrates are compared. Photovoltaic performance parameters of cells formed on the best polycrystalline material are essentially identical to those of a representative single crystal device.

THICK-FILM METALLIZATION FOR SOLAR CELLS – A PROGRESS REPORT

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Solar cell metallization is discussed in light of the long-range cost reduction goals which are necessary to help bring the photovoltaic industry to maturity. The leading metallization candidates are evaluated in terms of technical and economic merit. A cost sensitivity analysis is applied to present solar cell design in comparing aluminum, the least expensive alternative, to silver conductor. Test results are presented for electrical performance, manufacturability and reliability which led to the use of aluminum for the back contact in the present evolutionary phase of solar cell development.

THICK FILM SENSORS

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Making use of advantages of thick film technology, we have developed the following sensors with high sensitivities and reliabilities for consumer products, automobiles, and industrial instruments.

(1) *Temperature sensor* Thick film thermistors composed of spinel type oxide, RuO_2, and glass have been developed. The ranges of the resistivity and the thermistor constant are 1 Ω-cm – 10 MΩ-cm and 100 – 4500 K, respectively. A platinum thick film resistor, whose TCR is +3840 ppm/K, has also been developed for the sensor.

(2) *Radiant heat sensor* The sensor is composed of two thick film thermistors. One of them is covered by an aluminum film, and the other is carbon-coated. A highly sensitive sensor is realized in the composition of $Mn_{1.5}CoNi_{0.5}O_4$ – RuO_2 – glass.

(3) *Air-velocity sensor* Two kinds of hot-wire type air-velocity sensors with high precision have been developed. One of them consists of a laser-cut, spiral, platinum thick film formed on the surface of a ceramic cylinder. The other is a thick film thermistor (TCR: –6000 – –500 ppm/K) fabricated on a ceramic cylinder with a prefired conductor pattern.

(4) *Gas sensor (Alcohol sensor)* An alcohol sensor with high sensitivity (ΔR: 25%/200ppm) and short response time (0.2 sec.) have been developed. Alchohol gas is detected in the resistance change of the $LaNiO_3$ – glass (HG 1020) thick film sensor heated up to 300°C by a platinum thick film resistor.

(5) *Humidity sensor* Humidity sensors with high sensitivities (β: –3.1, –2.3) have been developed, composed of $CoAl_2O_4$ and the other of $ZrCr_2O_4$.

UNDERSTANDING NTC THERMISTORS

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Although thermistors have been in existence since 1932, their basic nature is not widely understood. For example, it is often assumed that the resistance of a thermistor responds to changes in temperature in much the same manner as an ordinary resistor. Such a misconception can result in improper specifications and a failure to fully utilize device capabilities. In this paper the semiconductor nature of NTC thermistors is discussed and the material constant, β, explained. Some thermistor characteristics which must be considered in circuit design are described. Fundamental examples of thermistor-resistor networks are presented to illustrate typical thermistor applications.

HIGH TEMPERATURE HYBRIDS FOR USE UP TO 275°C – DRIFT AND LIFETIME

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This paper reviews the drift and lifetime performance of 275°C hybrid microcircuits that were recently developed by Teledyne Philbrick and Sandia National Laboratories. This hybrid technology is based on temperature tolerant thick films and discrete silicon JFETs. The results of high temperature circuit testing are reviewed; component and circuit degradation and failure modes are described and compared to predictions; and finally, design rules are given to maximize lifetimes and to minimize performance drift for up to 10,000 hours of operation at 275°C. Although these circuits were developed for instrumenting geothermal boreholes, many other applications for this technology exist in such areas as fossil fuel exploration and production systems, jet engine monitors, and nuclear reactor monitors.

THICK FILM COPPER AND DIELECTRIC FOR MULTILAYERED CERAMIC

Isao Shibata, Kohji Nihei, *OKI Electric Industry Company, Ltd., Electronic Materials Department Research Laboratory, Tokyo, Japan*

The semiconductor elements and parts of electronic apparatus have made rapid technical progress over the last 20 years in order to cope with the demand for miniaturization and higher reliability of the apparatus. A high density wiring on a substrate packaging with highly integrated elements is needed to satisfy the demand, and this leads to a multilayered structure of wiring for the high density wiring.

The present report deals with a low cost thick film for multilayered ceramic boards that is suitable for packaging highly integrated elements, wiring density and heat conductivity.

PRODUCING COMPLEX HYBRIDS WITH INTEGRITY

Robert J. Ost, *Sperry Gyroscope Co., Great Neck, Long Island, N.Y.*

A new technology has given a breakthrough in manufacturing Complex Multilayer Hybrids free from short and open circuits. An electro-chemical patented method provides the key to 100% testing a multiplicity of substrates simultaneously. The test equipment, known as *S*ubstrate *I*ntegrity *T*est *E*quipment or S.I.T.E., uses a visual means to

compare a known "good" substrate with those under test. A single probe is located on the same nodal circuit point on each substrate. The equipment provides a significant color change for all points connected to the nodal network and by visual comparison with a good substrate, shorts and opens can be readily identified. By use of S.I.T.E. a low cost, flexible 100% Test Method is now possible which enables one to fabricate complex hybrids with confidence.

THERMAL CHARACTERIZATION OF SINGLE CHIP INTEGRATED CIRCUIT PACKAGES

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It has been found that the duct Reynolds number has a definite effect on the coefficient of convection (h) for the package itself, although the test program was conducted within laminar flow region (before transition region) as defined by the package Reynolds number.

If the experiments for determining the package characteristics are performed beyond the transition region of the duct, then an expression of form $R = a + b/\sqrt{V}$ provides a very good representation of the package's thermal performance in a free-flow field (i.e., no board or other packages).

The above expression is also a good predictive tool provided b is redetermined for mounting influence. However, this needs to be only a single point (velocity) average velocity experiment. It is not necessary to precisely measure the velocity at the package or even make measurements at more than one velocity as long as the proposed extrapolation will be confined to the duct region (laminar or turbulent) in which the single point measurement is made.

THE EFFECTS OF FILM THICKNESS ON CURRENT NOISE AND CONDUCTIVITY OF THICK FILM RESISTORS

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Variation of sheet resistivity and noise index of resistors made of EMCA5514 thick film resistor ink as a function of film thickness, t, was studied. It was found experimentally that the sheet resistivity, R_s, and the noise index, N.I., follow the relations $R_s = C_1 t^{-n}$ and $\text{N.I.} = A - 10 \log(wlt^{\beta})$ respectively. C_1 and A are constants, lw is the resistor surface area and $n \simeq 1.4$, $\beta \simeq 2$. These results show that the bulk resistivity of the resistor material decreases as the distance measured from the substrate increases. The reason for $\beta \neq 1$ is explained analytically in this paper and it is mainly due to the non-uniform resistivity of the resistor material.

THERMOSONIC GOLD WIRE BONDING TO SILVER BEARING CONDUCTORS

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Recent large increases in the price of precious metals have led to renewed interest in non-gold bearing thick film conductors. One of the requirements for such a replacement conductor is ease of wire bonding and wire bond reliability to make them useful for microcircuit applications. Experiments conducted by Kristi James and reported in the December 1977 issue of the "IEEE Transactions on Parts, Hybrids, and Packaging" demonstrated reliable thermosonic gold wire bonds made to silver plated surfaces.(1)

Studies have been completed to characterize thermosonic gold wire bonding to thick film silver, palladium-silver, platinum-silver, and platinum-palladium-silver conductors. The tests include: automatic wire bondability, initial pull strength, and high temperature storage. For the automatic wire bonding tests, 5000 wires were bonded per conductor-firing history combination with results of 5 or fewer misses for each combination. Excellent initial pull strengths were obtained with all failures in the wire. High temperature storage was conducted at 150°C and 200°C and pull tests, performed after 100, 250, 500, 1000 and 2000 hours. These showed no significant change in bond strength. A scanning electron microscope was used to verify the integrity of wire bonds after storage.

The data obtained show that thermosonic gold wire bonding is a feasible and reliable bonding technique for silver bearing thick film conductors.

(1) K. James, *I.E.E. Trans.* PHP–13. pp 419–425 (1977).

THERMAL DESIGN CRITERIA FOR PORCELAINIZED STEEL VS. ALUMINA SUBSTRATES

Steven C. Hugh, *Boeing Aerospace Company, Seattle, WA.*

To produce reliable hybrid circuits on porcelainized steel substrates the thermal properties of this new substrate material must be understood. At present theoretical models lead to unsatisfactory results. Experimental techniques

such as thermocouple measurements and infrared thermography have therefore been used to obtain thermal data on porcelainized steel and alumina substrates with various packaging schemes. Data thus obtained has lead to the conclusion that heat transfer in porcelainized steel is aided by the thermal spreading characteristics of the steel, but this advantage cannot be realized by small heat sources due to the thermal resistance of the porcelain. The heat spreading angle for various size heat sources has been discussed for porcelainized steel and alumina substrates.

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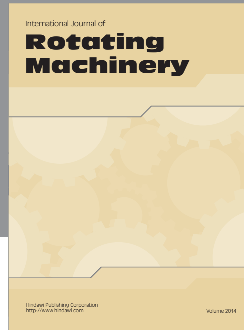
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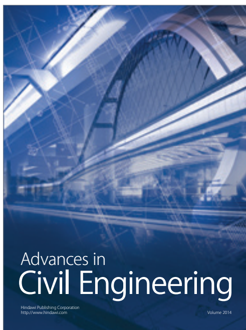
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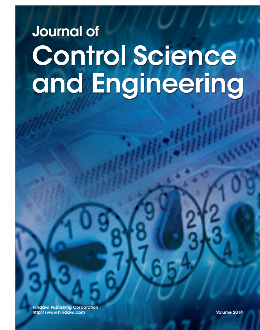
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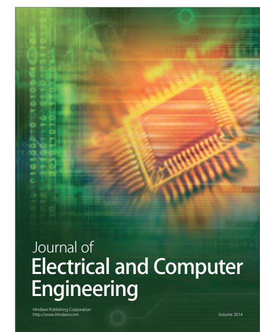
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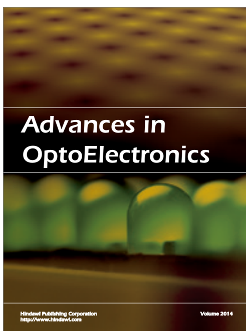
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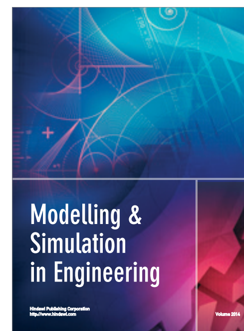
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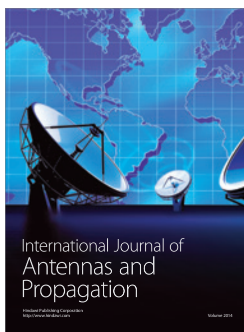
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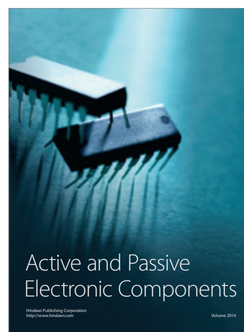
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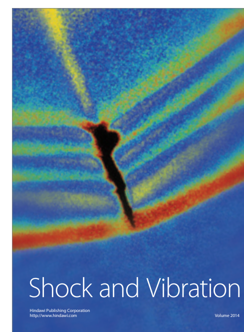
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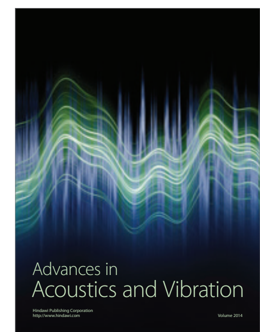
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