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Alloyed Contacts to Thick, Large Area Semiconductor Devices

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Severe damage has been found to occur in silicon when the conventional alloying technique is used to form contacts to very thick samples of large area. The usual alloying procedure has been modified by the use of separate silicon spacers to apply pressure to the alloying foil. This modified technique combined with the use of an improved alloying jig which provides positive control of the temperature gradient, has enabled satisfactory contacts to be formed on samples up to 22 mm diameter and 4 mm thick.

1. Introduction

In semiconductor power device technology large area low resistance contacts are essential. The present work on contacts arose from an experimental programme on high voltage p-i-n diodes. One of the aims of this particular work was to carry out all processing at the lowest possible temperature in order to minimise contamination and thereby, hopefully, maintain the carrier lifetime at a high value. This low temperature requirement precluded the use of diffusion and alloying was therefore adopted as the contact forming process. The greater thickness of some of the samples investigated compared with those normally used in power devices, and the limitations imposed on the duration of the alloying cycle by the presence in the samples of the mobile dopant Li, led to severe damage when a conventional alloying process was used. The investigation of this damage, which must be present to a less marked degree in devices of more normal dimensions, and the modifications made to the alloying procedure in order to overcome it are the subject of this paper.

2. Design of the Apparatus

Alloying is a well established technique for forming contacts to silicon and various discussions of the processes involved have been given, e.g. [1] and [2]. For the purposes of this discussion the alloying of aluminium into p-type silicon will be considered.

The major difficulties in alloying to large area devices are firstly, inducing wetting of the alloying metal over the whole surface and, secondly, avoiding major damage to the silicon due to the mismatch in the expansion coefficients of the silicon and the eutectic alloy. In the standard alloying procedure a foil of Al or Al/Si eutectic alloy is used which, in order to induce wetting, is pressed firmly against the silicon surface. The reactivity of molten Al/Si limits the choice of materials which can be used to apply pressure to the alloy and the normal method is to use a Mo disc which has a coefficient of expansion reasonably matched to that of silicon. During alloying the Mo disc becomes firmly bonded to the sample and, in device manufacture, is used as an intermediate layer for bonding the sample to the heat sink. The basic arrangement for carrying out this type of alloying process is shown in fig. 1, essentially, it provides a means for pressing the alloy onto the surface, raising the system to the required temperature, and cooling under a temperature gradient such that silicon doped with the alloying element is regrown onto

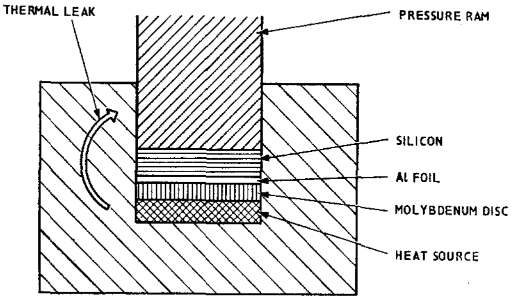

Figure 1 Schematic illustration of conventional alloying jig.

the parent crystal. This latter requirement is met by suitably designing the heat leak shown schematically in fig. 1. In most applications of this type of apparatus the silicon slice thickness would not exceed 0.5 mm and adequate control of the temperature gradient is obtained. Although in the present work the sample diameter of about 20 mm was comparable with that used in power devices with alloyed contacts, the sample thickness was required to vary from 1 to 4 mm. In these thicker samples it became extremely difficult to maintain the required temperature

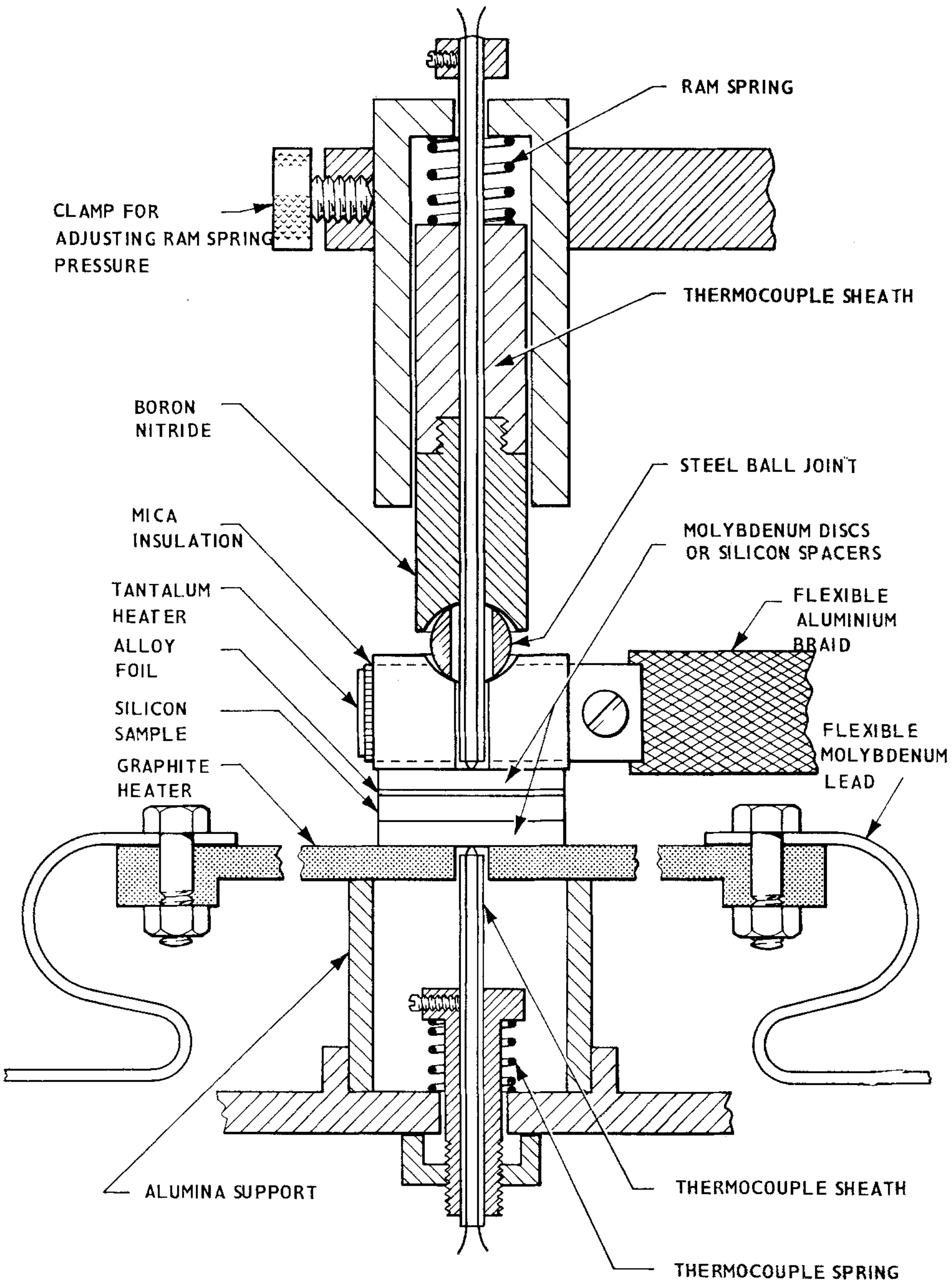

Figure 2 Alloying jig.

gradient at all stages of the cycle. An apparatus was therefore constructed which permitted independent heating of both faces of the sample and consequently allowed positive control of the temperature gradient at all stages of the alloying process.

The detailed design of the apparatus is shown in fig. 2. Both the graphite and tantalum heaters are operated resistively and the temperature is controlled so that alloying takes place only on the top surface of the sample. In the particular devices being studied Al was used to contact the *p*-type layer and Au/Sb for the *n*-type. Consequently by alloying the higher temperature Al contact first and turning the sample over, the second contact could be alloyed without disturbing the first. The heaters are controlled manually and to facilitate control of the temperature gradient the outputs of both thermocouples are displayed on the same chart recorder by using a repetitively switched input. A vacuum of better than 10^{-5} torr is maintained around the apparatus during alloying.

3. Alloying Results

The first attempts at alloying were carried out in samples 1 mm thick using 0.5 mm thick Mo discs. All alloying was carried out on (111) faces. The normal cleaning procedures as described in [2] were used and successful alloying was obtained in all cases. Although most of the *p-n* junction devices formed using these contacts showed satisfactory forward and reverse bias behaviour, occasionally devices were obtained which showed very poor reverse characteristics which could not be attributed to surface effects. When the silicon slice thickness was increased to 3 mm all the devices obtained were found to exhibit this poor reverse bias behaviour. The source of these failures was traced to cracks which originated at either the Al or Au alloy interface and ran along (111) planes into the silicon. An example is shown in fig. 3.

There is evidence [2] that wetting is aided by maintaining the alloy at a higher temperature than the silicon at all stages of the heating cycle. A temperature difference of 50° C was therefore maintained between the top and bottom faces of the sample throughout the cycle. In such cases the top surface of the sample was in compression and the bottom surface in tension. To eliminate this source of stress, experiments were carried out in which, by careful control of the heaters, the sample was taken to the alloying temperature with no measurable temperature difference across it and then cooled with only a 10° C temperature differential during the regrowth period. Cracks were however again found in these samples.

The other suspected cause of cracking was the rigidly bonded Mo disc which restricts relaxation of the eutectic alloy and could lead to large stresses. Other materials which can be used to press the alloy foil onto the surface without bonding are limited. In order to avoid excessive temperature drops in the jig any non-metallic material used must be extremely thin. Al_2O_3 would be expected to be satisfactory from the chemical viewpoint and some experiments were carried out with slices sawn from a bar of high purity, recrystallised alumina and lapped to 75 μm thickness. In all cases however the alumina became firmly bonded to the sample. This may have been due to porosity, enhanced by particle displacement during sawing, rather than true chemical attack. Single crystal Al_2O_3 would

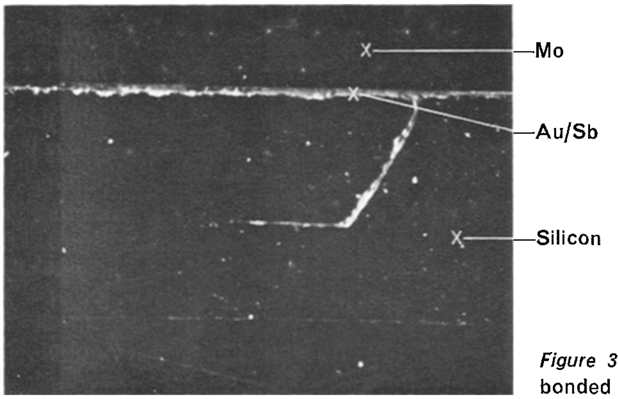

Figure 3 Crack formed at Au/Sb alloy interface when bonded to Mo disc (× 25).

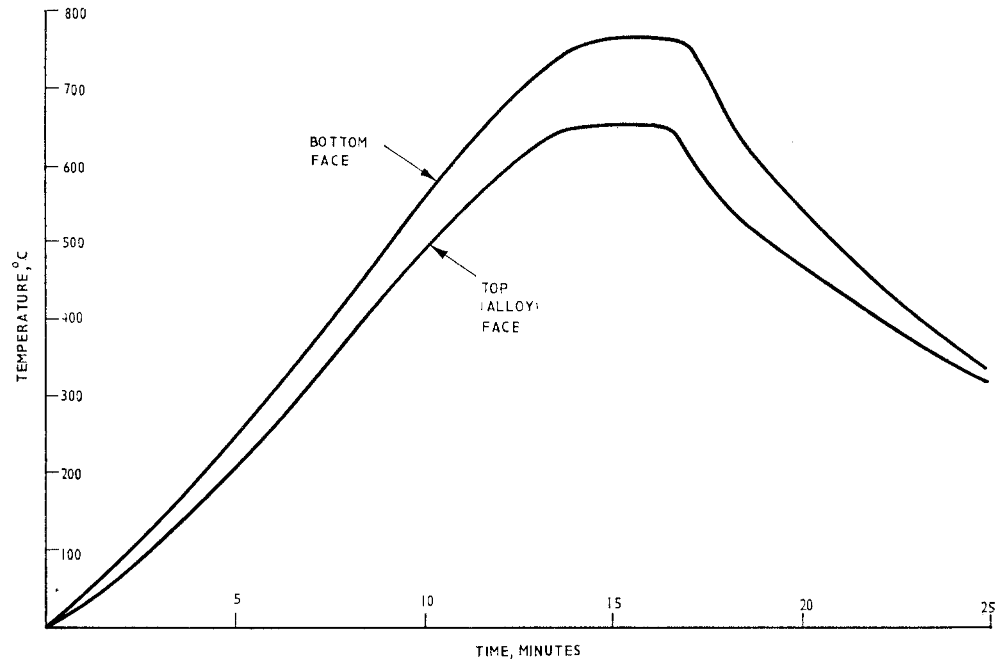

Figure 4 Typical temperature-time cycle for alloying aluminium on 3 mm thick sample.

obviously be preferable but was not readily available in adequate size. Another chemically attractive alternative is Si_3N_4, but again the porosity of available material made it unacceptable.

The method finally adopted to eliminate strain induced by the Mo discs was to replace them by separate silicon slices lapped to 100 μm thickness. Alloying was then carried out in the normal way with the result that these thin silicon discs became firmly bonded to the sample. The excess silicon was then progressively lapped away and the surface resistivity repeatedly checked until the underlying Al/Si eutectic was exposed. Final contact was then made to this layer by electroless nickel plating. A typical temperature-time cycle used for alloying an aluminium contact onto a 3 mm thick sample is shown in fig. 4 and an example of the Al/Si interface is shown is fig. 5.

Although some damage to the silicon spacers has been detected, possibly due to the effects of the ram on this thin piece of material, no damage to the underlying silicon has been observed. All the *p-n* junction devices fabricated with this type of contact have shown satisfactory

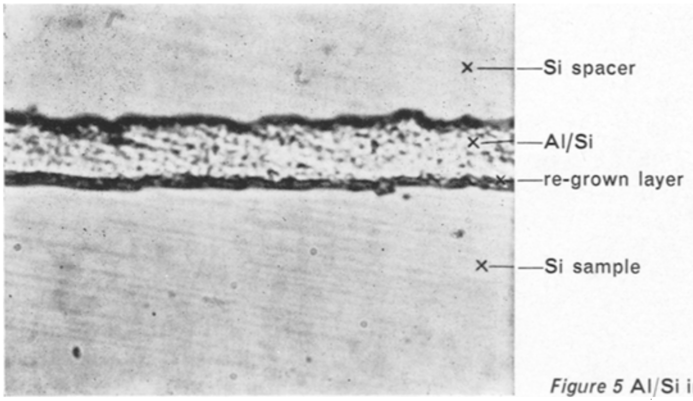

Figure 5 Al/Si interface made with Si spacer (× 600).

reverse bias behaviour and the contact resistances under forward bias have also been found to be quite satisfactory.

4. Conclusions

The conventional arrangements used for alloying contacts to silicon can lead to severe damage when applied to very thick samples of large area. This damage can be avoided by using separate silicon spacers for applying pressure to the alloy foil in conjunction with the apparatus described, which allows positive control of the temperature distribution in the sample.

Acknowledgement

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