Electrical and mechanical characterisation of Si/Al ohmic contacts on diamond

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A new ohmic contact technology on diamond with low resistivity is presented. A Si/Al metallisation is used and leads to a 7×10^{-6} $\Omega.cm^2$ specific contact resistivity, measured by the transfer length method. Comparison is made between this technology and the Ti/Pt/Au traditional technology. Both technologies show very good electrical, thermal and mechanical characteristics.

Introduction: Diamond is well known to be a promising material for power electronics. Its wide bandgap, high breakdown field, thermal conductivity and electrical carrier mobility are particularly well fitted to high voltage, high temperature and high power device fabrication requirements [1]. Still, many technological issues need to be solved to make proper use of diamond to manufacture competitive electronic devices.

Many researches have focused on the deposition of ohmic contacts on diamond. In particular, AlSi (99:1) based contacts gave, to our knowledge, the best electrical characteristics [2]. However, Ti-based contacts are more widely used because the thick TiC layer that is formed during the contact annealing provides both good low contact resistivity and good mechanical adhesion [3–5].

Here, a Si/Al multilayer metallisation was used. The use of a thick silicon layer allows the formation of a strong bonding SiC layer, which is important if diamond device packaging is wanted. Transfer length method (TLM) measurements were performed and compared to TLM measurements made on Ti/Pt/Au contacts. Mechanical tests have been made to compare the mechanical properties of the coatings and to assess their adherence to diamond substrates.

Experimental details: A 1.5 μm-thick heavily boron-doped diamond film deposited on a 3×3 mm^2 1b diamond sample was used in this study. The boron density in the film is approximately 3×10^{20} cm^{-3}. Its square resistivity was measured by four probes measurement to be about 110 Ω/□. The sample was primarily coated with a 200 nm heavily boron-doped silicon layer deposited in a plasma enhanced chemical vapour deposition (PECVD) reactor. It was then annealed in a 1200 °C hot furnace for 10 s in order to produce a strong bonding SiC layer at the diamond/silicon interface. TLM patterns with 5, 10 and 50 μm-long Al contacts (500 nm thickness) were fabricated using inductively coupled plasma reactive ion etching and metal deposition by evaporation and lift-off, as shown in Fig. 1. Finally, the contacts were annealed in a 450 °C furnace for 20 mn. On the other hand, Ti/Pt/Au (50nm/50nm/500nm) TLM patterns were fabricated, annealed to 500 °C for 1 h, and I(V) measurements were performed so that comparison could be made.

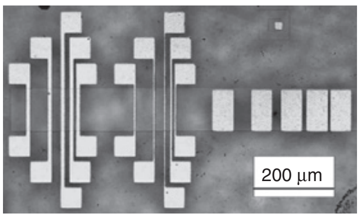

Fig. 1 *Si/Al TLM patterns fabricated on diamond film*

The mechanical behaviour of the coating films and the adherence properties of the contacts were investigated through nano-indentation and nano-scratching tests. Indentation tests with a three-sided pyramidal Berkovich tip were carried out using a commercial indentation system (NanoIndenter XP, MTS). The principle is to penetrate the nanometric tip into the deposited layers according to a load/unload cycle by applying a maximal load of 1600 mN. Once the loading–unloading curve was extracted, the values of hardness and elastic moduli were determined applying the procedure proposed by Oliver and Pharr [6] and assuming a Poisson's ratio of 0.33 for the Si/Al sample and 0.42 for the Ti/Pt/Au sample [7]. This technique was chosen because it allows the properties to be determined directly inside the different coating layers avoiding macroscopic samples.

Nano-scratching tests were performed using the same apparatus equipped with a Berkovich diamond stylus (point-on orientation). Scratches with 500 μm lengths were made by translating a small sharp tip on the sample surface under linearly increasing load from 0.1 to 80 mN and horizontal speed of the sample table of 10 μm s^{-1}. We then recorded the applied scratch load against the displacement into the surface. Associated with microscopic observations, these tests allowed evaluating the adherence between layers and substrate.

Results and discussion: Measurements carried out on the Ti/Pt/Au TLM structures indicated a contact resistivity $\rho_C = 2 \times 10^{-6}$ $\Omega.cm^2$. I(V) measurements performed on the Si/Al TLM test structures showed very good ohmic behaviour. Specific contact resistivity and square sheet resistivity are extracted from R(L) characteristics (Fig. 2). The contact resistivity and square resistivity are $\rho_C = 7 \times 10^{-6}$ $\Omega.cm^2$ and $R_{SH} = 105$ Ω/□, respectively. The transfer length was estimated to be $L_T = 2.3$ μm. In both cases, contacts showed no sensibility to temperature, which is due to the very high doping level of the diamond film.

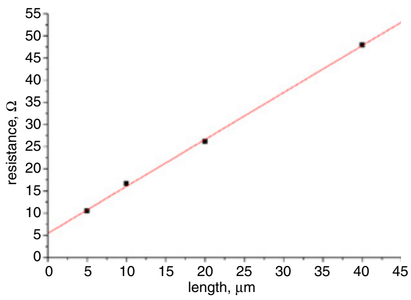

Fig. 2 *Resistance against inter-contact spacing extracted from 50 μm length TLM*

The nano-indentation test results of Si/Al coatings, presented in Fig. 3, were comparable to those of Ti/Pt/Au coatings. The small slope at the beginning of the loading–unloading curve is due to low stiffness and hardness of both types of coatings compared to diamond. The rigidities of the upper Au and Al layers are, respectively, 102 ± 12 GPa and 64 ± 16 GPa. Their hardnesses are, respectively, 1 ± 0.16 GPa and 0.97 ± 0.3 GPa. The obtained values are close to those indicated in [8, 9].

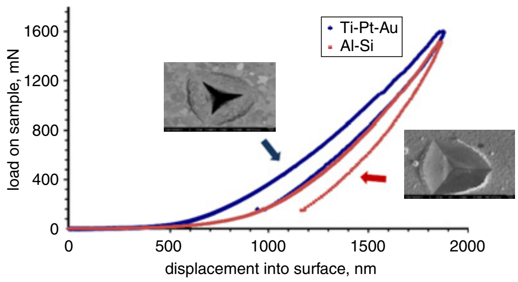

Fig. 3 *Nano-indentation curves for Ti/Pt/Au and Si/Al coatings*

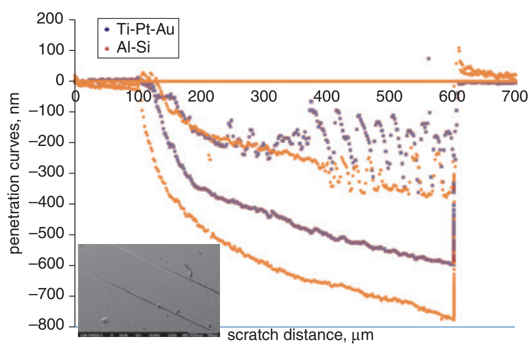

Fig. 4 *Nano-scratching curves for Ti/Pt/Au and Si/Al coatings*

The scratching profiles of the coatings are shown in Fig. 4. No cracking is noted in the bottom and at the edge of the stripe in spite of the strong load applied. No interfacial delamination between the coating and the diamond substrate is observed. Thus, we can estimate that the layer adhesion is greater than their own cohesion.

Conclusion: New Si/Al contacts were fabricated and characterised using electrical and mechanical tests. Low contact resistivity and, good thermal stability, as well as excellent interfacial and tribological properties, were observed. This contact technology is well suited for use in power electronic applications. Moreover, a major benefit of this Si/Al technique is that it is compatible with classical silicon device packaging.

6 April 2010
doi: 10.1049/el.2010.0803
One or more of the Figures in this Letter are available in colour online.

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