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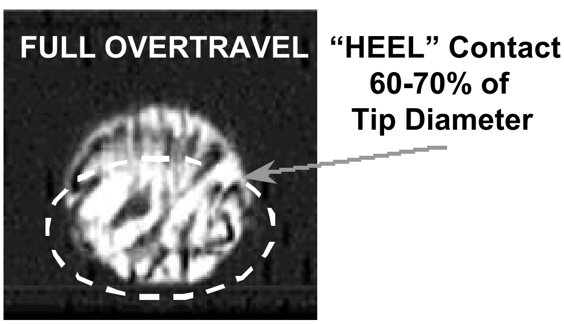
Fundamentals of Contact Resistance, Part II – Localized Joule Heating

It is not difficult to create sufficient electrical contact for some level of current to flow between a probe tip and the aluminum contact pad. Difficulties, however, arise in maintaining the "quality" of the inter-metallic contact over a large number of repeated scrubs. Across the contact area, all current is forced to flow through narrow conductive interfaces, or a-Spots, with radii of a few microns. The resulting current densities ($>10^6$ A/m^2) cause high levels of localized Joule heating at relatively low levels of forcing current.

The "real" contact area of a probe needle is significantly smaller than the observed scrub mark area. Images taken through the sapphire window of a probe card analyzer show at full overtravel the estimated "heel" contact area is approximately 60–70% of the tip of the probe tip diameter.



(Image courtesy of Applied Precision, Inc.)

Within the contact area, current flow is constricted to minute inter-metallic contacts, commonly referred to as "a-Spots". Generally, any electrical contact is believed to contain some number of a-Spots. Although these areas cover a very small fraction of the contact surface, the localized processes that occur dramatically influence the reliability of the electrical contact.

Contact resistance (C_{RES}) between probe tip and contact substrate is comprised of a constriction resistance which is a function of the probe and substrate resistivities ($\rho_{probe} + \rho_{substrate}$), the number and diameter of the contact a-Spots ($n \times a$) as well as the oxide film resistance ($\sigma_{oxide\text{-}film}$) over the contact area ($A_{contact}$). In general C_{RES} between two materials is described by Equation 1 [Holm, 1967].

During production-level probing, thin oxide films, as well as other complex contaminants, can exist on the probe tip

$$C_{RES} = \overbrace{\frac{(\rho_{probe} + \rho_{substrate})}{4na}}^{CONSTRICTION-RESISTANCE} + \underbrace{\frac{\sigma_{oxide-film}}{A_{contact}}}_{FILM-RESISTANCE}$$

and bond pad surfaces. These form insulating or semi-conducting regions within the contact area. Thus, as the a-Spot sizes decrease, the constriction resistance increases; concomitantly, as the oxides grow, the film resistance contribution increases. Together these effects will significantly affect the magnitude and stability of C_{RES} during wafer test.

Localized Joule heating and power dissipation occurs at the inter-metallic a-Spot contacts. The resulting a-Spot temperature is defined as a function of the interfacial voltage drop and the conducting medium material properties. A first order approximation of the a-Spot temperature ($T_{a\text{-}Spot}$) at the interface of the probe tip and aluminum contact pad can be made [Carbonéro, 1995]:

$$T_{a-Spot} = T_{Bulk} + \sqrt{\frac{U^2}{4\alpha\rho\lambda} + \frac{1}{\alpha}} - \frac{1}{\alpha}$$

where, U is the voltage drop (U = forcing current × C_{RES}), T_{Bulk} is the ambient temperature, a and r are the temperature coefficient of resistivity and the resistivity at the bulk temperature, and l is the thermal conductivity.

In summary, when current flows between a probe tip and bond pad it is constricted and forced to flow through minute conducting a-Spots. For some probe materials, the high-localized temperatures caused by the interfacial voltage drop can result in rapid oxidation around the periphery of the contact a-Spots. These localized effects contribute to the increased and unstable C_{RES} at each measurement interval. Higher test temperatures, greater forcing currents and additional surface contaminants experienced during production-level probing will exacerbate these effects

Selected References –

R. Holm, Electric Contacts, Springer-Verlag, (1967).
J.L. Carbonéro, et al., *IEEE Trans. Microwave Theory and Tech*., **43** (1995).