

Contents

Nomenclature	xi
1 Introduction	1
1.1 Packaging of semiconductor power modules	2
1.2 Bond-position-depending joining conditions and challenges	5
1.3 Classification of wire bonding into joining technologies	6
1.3.1 Commonly-used cold welding processes	6
1.3.2 Ultrasonic based joining technologies	7
1.4 Contribution of this thesis	9
2 State of scientific knowledge of wire bonding processes	11
2.1 Functioning of ultrasonic wire bonding	11
2.1.1 Vibration system of ultrasonic wire bond machines	13
2.1.2 Functionality and materials of wire bonding tools	18
2.1.3 Ultrasonic softening effect	21
2.1.4 Material characteristics of copper wires and copper substrates	25
2.1.5 Determination of joining quality	27
2.2 Friction modeling of solid bodies	31
2.2.1 Surface friction modeling	31
2.2.2 Abrasion modeling	35
2.3 Contributing factors for cold weld processes	36
2.3.1 Contaminant and oxide layers	36
2.3.2 Plastic deformation and surface approaching	38
2.4 Modeling approaches for different cold weld processes	38
2.4.1 Modeling of the ball/wedge wire bonding process	40
2.4.2 Modeling of the wedge/wedge wire bonding process	42
3 Friction approach for modeling the joining process	47
3.1 Estimating the ultrasonic softening effect	58
3.2 Modeling the pre-deformation of wire and substrate	59
3.3 Elasto-plastic deformation during wire bonding	62
3.4 Predicting the normal pressure distribution in the contact areas	64
3.4.1 Influence of the tool excitation on the pressure distributions	66
3.4.2 Influence of the adhesion on the pressure distributions	67
3.4.3 Influence of the tool geometry on the normal pressure distribution	68
3.5 Modeling the clamping of tool and wire	72
3.5.1 Modeling approach to determine tangential force transmission characteristics of bond tools	75
3.5.2 Tool-shape-dependent transmittable tangential forces	77

3.5.3	Implementation of tangential-force displacement curves into analytical model	80
3.6	Modeling the friction between wire and substrate	80
3.6.1	Determination of contact stiffness between wire and substrate . .	82
3.6.2	Masing model	84
3.6.3	Coupled point contact element simulation	86
3.7	Metallic joint forming model for predicting micro welds	97
3.8	Predicting the bonding quality and the shear force value	102
3.9	Experimental validation of the wire bond model	107
3.10	Summary and comparison of the friction model approach to published models	115
4	Substrate deformation and substrate vibration induced disturbances	117
4.1	Influence of static mechanical deformation on the bond quality	118
4.1.1	Mechanical fixation of molded connector pads in power semiconductor modules	118
4.1.2	Measuring and modeling of the quasi-static mechanical deformation of power semiconductor modules	121
4.1.3	Influence determination of tilting angle on the bond quality	122
4.2	Influence of substrate vibrations on the bond quality	131
4.3	Influences of power module vibrations on the bond quality	138
4.3.1	Influence of clamping device on the mechanical bond position properties	141
4.3.2	Measuring and modeling of module vibrations	144
4.3.3	Model to predict substrate vibration influences on the bond quality	150
5	Summary and Conclusions	157
	Bibliography	161