BONDING TOOL WITH IMPROVED WORKING FACE

FIELD OF THE INVENTION

[0001] The present invention relates to wire bonding systems and, more particularly, to improved bonding tools for wire bonding machines.

BACKGROUND OF THE INVENTION

[0002] In the processing and packaging of semiconductor devices, wire bonding continues to be the primary method of providing electrical interconnection between two locations within a package (e.g., between a die pad of a semiconductor die and a lead of a leadframe). More specifically, using a wire bonder (also known as a wire bonding machine) wire loops are formed between respective locations to be electrically interconnected.

[0003] An exemplary conventional wire bonding sequence utilizing ball bonding includes: (1) forming a free air ball on an end of a wire extending from a bonding tool; (2) forming a first bond on a die pad of a semiconductor die using the free air ball; (3) extending a length of wire in a desired shape between the die pad and a lead of a leadframe; (4) stitch bonding the wire to the lead of the leadframe (forming a second bond); and (5) severing the wire. In forming the bonds between (a) the ends of the wire loop and (b) the bond site (e.g., a die pad, a lead, etc.) varying types of bonding energy may be used including, for example, ultrasonic energy, thermosonic energy, and thermocompressive energy, amongst others. As is known to those skilled in the art, this sequence is exemplary in nature, and the order may be changed in a given application (e.g., the first bond may be formed on the substrate, etc.).

[0004] Each of the following U.S. patents relates to the field of bonding tools for wire bonding machines: U.S. Patent No. 7,004,369 entitled "Capillary with Contained Inner Chamfer"; U.S. Patent No. 6,966,480 entitled "Concave Face Wire Bond Capillary and Method"; U.S. Patent No. 6,439,450 entitled "Concave Face Wire Bond Capillary"; U.S. Patent No. 6,158,647 entitled "Concave Face Wire Bond Capillary"; U.S. Patent No. 5,844,830 entitled "Capillary for a Wire Bonding Apparatus"; U.S. Patent No. 5,871,141

entitled "Fine Pitch Bonding Tool for Constrained Bonding"; U.S. Patent No. 5,662,261 entitled "Wire Bonding Capillary"; U.S. Patent No. 5,421,503 entitled "Fine Pitch Capillary Bonding Tool"; and U.S. Patent No. 4,911,350 entitled "Semiconductor Bonding Means Having an Improved Capillary and Method of Using the Same."

[0005] FIG. 1A is an illustration of a well-known prior art fine pitch bonding tool 100 (e.g., a capillary bonding tool). Bonding tool 100 includes cylindrical portion 102, tapered portion 104 adjacent cylindrical portion 102, and working tip 106 adjacent the end of tapered portion 104. Passage 108 extends from upper end 110 to working tip 106 of bonding tool 100. Passage 108 is configured to receive a length of wire for use in a wire bonding operation. In FIG. 1A (and other figures provided herein), passage 108 is illustrated as being tapered from upper end 110 to working tip 106, and is also illustrated as including cylindrical section 116 and chamfer 112; however, it is understood that various types of passages with various shapes and configurations are known to those skilled in the art.

[0006] FIG. 1B is an illustration of an enlarged sectional view of working tip 106. As shown in FIG. 1B, tapered portion 104 has a substantially constant taper starting from the point at which it meets cylindrical section 102 (as shown in FIG. 1A). Working tip 106 defines working face 120 having face angle 118 of, for example, between 8 and 15 degrees. Adjacent working face 120 is inner chamfer 112 having an overall angle 114 of, for example, less than 90 degrees in order to provide a first bond (ball bond) that meets shear and pull test requirements. Cylindrical passage 116 is between the upper portion of chamfer 112 and the remainder of passage 108. Moreover, cylindrical passage 116 and chamfer 112 are generally defined as part of passage 108.

[0007] FIG. 2A is an illustration of working tip 106 of bonding tool 100 forming a second bond of a wire loop, where the second bond includes stitch bond 128 and tail bond 126. As explained above, after a free air ball of wire 122 is bonded to a pad on a semiconductor device (not shown), bonding tool 100 then handles wire 122 during looping, feeding wire 122. Bonding tool 100 then forms the second bond, including stitch bond 128 and tack or tail bond 126 on supporting substrate 124 to interconnect the semiconductor device (not shown) to supporting substrate 124.

[0008] A wire tail (not shown) is then formed so that the entire wire bonding process may be repeated. To form the wire tail, a wire clamp (not shown) is open as bonding tool 100 is raised to a predetermined height, during which time tail bond 126 remains affixed to supporting substrate 124. The wire clamp is then closed and

bonding tool is raised causing tail bond 126 to separate from support substrate 124 (as represented by torn tail area 126a in FIG. 2B). Generally, tail bond 126 acts as a temporary anchor point during formation of the wire tail, resulting in repeatable wire tail lengths.

[0009] FIG. 2B is a partial cross-sectional plan view of the illustration of FIG. 2A. Feature 130 represents a section of working tip 106 of bonding tool 100 that essentially separates tail bond 126 and stitch bond 128. For example, a full tail bond 126 with a relatively small torn tail area 126a represents a favorable tail bond 126. In other words, a stronger tail bond 126 is desirable to adequately anchor wire 122 during the wire tail formation. As will be understood by those skilled in the art, FIG. 2B (and various other detail views provided herein) are not to the same scale as FIG. 1B so that additional detail of FIG. 2B may be shown.

[0010] An inadequate tail bond 126 (e.g., a tail bond that is not strong enough) may result in tail bond 126 separating from supporting substrate 124 during raising of bonding tool 100 before bonding tool 100 reaches the predetermined height, resulting in a wire tail that is too short (also referred to as a "short tail"). Problems such as short tails, and other problems at the second bond, undesirably tend to result in inconsistent wire tails used to form the subsequent free air bails.

[0011] Thus, it would be desirable to provide improved bonding tools with improved working faces to form improved second bonds.

SUMMARY OF THE INVENTION

[0012] According to a first aspect of the present invention, there is provided a bonding tool configured for engagement with a wire bonding machine, the bonding tool comprising: a body portion, the body portion defining a passage configured to receive a length of wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, wherein during engagement with the wire bonding machine a segment of the working face extends downward with respect to a plane defined at an intersection of the passage and the working face.

[0013] According to a second aspect of the present invention, there is provided a bonding tool configured for engagement with a wire bonding machine, the bonding tool comprising: a body portion, the body portion defining a passage configured to receive a length of wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, the working face comprising a plurality of segments, wherein during engagement with the wire bonding machine a segment of the working face directly adjacent the end of the passage extends downward with respect to a plane defined at an intersection of the passage and the working face, and another segment of the working face directly adjacent the segment extends at an upward angle with respect to the plane defined at the intersection of the passage and the working face.

During engagement with the wire bonding machine, a segment of the working face directly adjacent the end of the passage extends downward with respect to a plane defined at an intersection of the passage and the working face, and another segment of the working face directly adjacent the segment extends at an upward angle with respect to a plane defined at an intersection of the passage and the working face.

[0014] According to a third aspect of the present invention, there is provided a method of forming a wire bond, the method comprising the steps of: (1) forming a free air ball on an end of a wire extending from a bonding tool; and (2) bonding the free air ball to a bonding location to form the wire bond using the bonding tool, the bonding tool comprising a body portion, the body portion defining a passage configured to receive a length of the wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, wherein during bonding a segment of the working face extends downward with respect to a plane defined at an intersection of the passage and the working face.

[0015] Further, the present invention may be embodied as a wire bonding machine for bonding a wire to a bonding location. Such a wire bonding machine includes a bonding surface configured to support a work piece to be wire bonded, as well as a bonding tool configured according to an exemplary embodiment of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The invention is best understood from the following detailed description when read in connection with the accompanying drawing. It is emphasized that, according to common practice, the various features of the drawing are not to scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawing are the following figures:

FIG. 1A is a cross-sectional view of a conventional bonding tool;

FIG. IB is a detail view of the working tip of the conventional bonding tool of FIG. 1A;

FIGS. 2A is a partial cross-sectional view of the working tip of a conventional bonding tool forming a bond on a supporting substrate;

FIG. 2B is a partial cross-sectional plan view of the conventional bonding tool of FIG. 2A;

FIG. 3A is a cross-sectional view of a bonding tool in accordance with an exemplary embodiment of the present invention;

FIG. 3B is a detail view of the working tip of the bonding tool of FIG. 3A;

FIG. 4A is a cross-sectional view of a bonding tool in accordance with another exemplary embodiment of the present invention;

FIG. 4B is a detail view of the working tip of the bonding tool of FIG. 4A;

FIG. 5A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 5B is a detail view of the working tip of the bonding tool of FIG. 5A;

FIG. 6A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 6B is a detail view of the working tip of the bonding tool of FIG. 6A;

FIG. 7A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 7B is a detail view of the working tip of the bonding tool of FIG. 7A;

FIG. 8A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 8B is a detail view of the working tip of the bonding tool of FIG. 8A;

FIG. 9A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 9B is a detail view of the working tip of the bonding tool of FIG. 9A;

FIG. 10A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 10B is a detail view of the working tip of the bonding tool of FIG. 10A;

FIG. 11A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 11B is a detail view of the working tip of the bonding tool of FIG. 11A;

FIG. 12A is a block diagram of a portion of a wire bonding machine in accordance with an exemplary embodiment of the present invention;

FIG. 12B is a detail view of the working tip of the bonding tool of the wire bonding machine of FIG. 12A;

FIG. 13A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 13B is a detail view of the working tip of the bonding tool of FIG. 13A;

FIG. 14A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention;

FIG. 14B is a detail view of the working tip of the bonding tool of FIG. 14A;

FIG. 15A is a cross-sectional view of a bonding tool in accordance with yet another exemplary embodiment of the present invention; and

FIG. 15B is a detail view of the working tip of the bonding tool of FIG. 15A.

DETAILED DESCRIPTION OF THE INVENTION

[0017] As explained above, repeatable wire tail lengths are desirable in the processing of semiconductor devices. Generally, a tail bond acts as a temporary anchor point during formation of the wire tail. According to certain exemplary embodiments of the present invention, an improved working face of the present invention enlarges the tail bond area, thereby improving the stability of the tail bond formation. More specifically, according to such exemplary embodiments, the area of the working face responsible for the tail bond is enlarged without compromising the geometries related to the first bond.

[0018] The working face of a working tip of a bonding tool has a significant impact on the formation of the tail bond portion of the second bond. Certain exemplary embodiments of the present invention relate to an improved working face in order to form an improved second bond with little or no impact on the first bond of the wire bonding sequence. In contrast to a positive face angle (e.g., angle 118 in FIG. 1B), according to certain exemplary embodiments of the present invention, at least a segment of the working face may be configured at a negative face angle. In such a negative face angle configuration, the segment may extend downward with respect to a plane defined at an intersection of the wire feed passage of the bonding tool and the working face (e.g., downward from the passage toward a bonding surface of a wire bonding machine). Alternatively, the segment extending downward with respect to the plane may be positioned at a portion of the working face that is not directly adjacent the end of the passage. For example, a planar (i.e., flat) segment of the working face may be positioned directly adjacent the end of the passage, while a negative face angle segment may be positioned directly adjacent the planar segment (See, e.g., FIGS. 16A-16B). Other configurations of a negative face angle segment are also contemplated.

[0019] Referring to FIGS. 3A and 3B, bonding tool 300 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 3A, bonding tool 300 is defined by a body portion including cylindrical portion 302 and tapered portion 304 adjacent an end of cylindrical portion 302. Tip portion 306 (i.e., working tip 306) is defined at an end of tapered portion 304. The body portion of bonding tool 300 defines passage 308 configured to receive a length of wire (not shown). Passage 308 extends from upper end 310 of bonding tool 300 to working tip 306. As will be understood by those skilled in the art, FIG. 3A (and various other detail views provided herein) is a partial sectional view, that is, the sectional view is simplified (to remove certain background lines) so that the inventive features are more clearly shown.

[0020] FIG. 3B is a partial (for the sake of clarity) cross-sectional enlarged view of working tip 306. Passage 308 extends to tip portion 306 of bonding tool 300, tip portion 306 defining working face 320 of bonding tool 300. More specifically, inner chamfer 312 of passage 308 terminates at working face 320. Inner chamfer 312 has inner chamfer diameter 324. Cylindrical passage 316 is positioned between an upper portion of chamfer 312 and the remainder of passage 308. Moreover, cylindrical passage 316 and chamfer 312 are generally defined as part of passage 308. A plane P is defined at an intersection I of passage 308 (more specifically, inner chamfer 312 portion of passage 308) and working face 320, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine. As used herein, the term

"bonding surface" may refer to a semiconductor die, a substrate or lead frame, or a surface of the wire bonding machine such as the heatblock, amongst others.

[0021] During engagement with a wire bonding machine, working face 320 directly adjacent the end of passage 308 (more specifically, directly adjacent inner chamfer 312) extends downward (i.e., at a downward angle 322 from plane P) with respect to plane P. Plane P is defined at intersection I of passage 308 (more specifically, directly adjacent inner chamfer 312) and working face 320. Downward angle 322 is also referred to as negative face angle 322, and is in a range of about 3 to 30 degrees with respect to plane P.

[0022] FIGS. 4A – 11B and 13A – 15B are views of working tips according to various other exemplary embodiments of the present invention. The configuration of each embodiment is very similar to that described with reference to FIGS. 3A and 3B, with the exception of the various working faces. Thus, certain respective details will be omitted, while details of the each of the working faces of the various embodiments will be described herein.

[0023] Referring now to FIGS. 4A and 4B, bonding tool 400 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 4A, bonding tool 400 is defined by a body portion including cylindrical portion 402, tapered portion 404, and tip portion 406 (i.e., working tip 406). The body portion of bonding tool 400 defines passage 408 that extends from upper end 410 of bonding tool 400 to working tip 406.

[0024] FIG. 4B is a partial cross-sectional enlarged view of working tip 406. Passage 408 (including cylindrical passage 416 and chamfer 412) extends to tip portion 406 of bonding tool 400, tip portion 406 defining working face 420 of bonding tool 400. More specifically, inner chamfer 412 (having inner chamfer diameter 424) of passage 408 terminates at working face 420. A plane P is defined at an intersection I of passage 408 (more specifically, inner chamfer 412 portion of passage 408) and working face 420, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0025] Working face 420 of tip portion 406 includes a plurality of segments, i.e., segment 420a and 420b. During engagement with the wire bonding machine, segment 420a directly adjacent the end of passage 408 (more specifically, directly adjacent inner chamfer 412 of passage 408) extends downward (i.e., at downward angle 422) with respect to plane P. Working face segment 420a has a negative face diameter 426

and a face length 428. Another segment 420b of working face 420 directly adjacent segment 420a extends at an upward angle 434 from an end of segment 420a away from a bonding surface of the wire bonding machine (not shown). Working face segment 420b has a face length 446.

[0026] Downward angle 422 of negative working face segment 420a is in a range of about 3 to 30 degrees with respect to plane P. Upward angle 434 of positive working face segment 420b is in a range of between about 0 to 30 degrees with respect to plane P. Each working face segment, 420a and 420b, comprises a length (428 and 446, respectively) in a range of about 0.1 to 2.1 mils.

[0027] Referring to FIGS. 5A and 5B, bonding tool 500 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 5A, bonding tool 500 is defined by a body portion including cylindrical portion 502, tapered portion 504, and tip portion 506 (i.e., working tip 506). The body portion of bonding tool 500 defines passage 508 that extends from upper end 510 of bonding tool 500 to working tip 506.

[0028] FIG. 5B is a partial cross-sectional enlarged view of working tip 506. Passage 508 (including cylindrical passage 516 and chamfer 512) extends to tip portion 506 of bonding tool 500, tip portion 506 defining working face 520 of bonding tool 500. More specifically, inner chamfer 512 (having inner chamfer diameter 524) of passage 508 terminates at working face 520. A plane P is defined at an intersection I of passage 508 (more specifically, inner chamfer 512 portion of passage 508) and working face 520, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0029] Working face 520 of tip portion 506 includes segment 520a. During engagement with the wire bonding machine, segment 520a directly adjacent the end of passage 508 (more specifically, directly adjacent inner chamfer 512 of passage 508) extends downward (i.e., at a downward angle 522) with respect to plane P. Working face segment 520a has a negative face diameter 526 and a face length 528. The remainder of working face 520 directly adjacent segment 520a extends at an upward angle from an end of segment 520a away from the bonding surface (not shown) and toward an outer radius OR of working tip 506. Downward angle 522 of negative working face segment 520a is in a range of about 3 to 30 degrees with respect to plane P. Working face segment 520a comprises a length 528 in a range of about 0.1 to 2.1 mils.

[0030] Comparing the exemplary embodiment of bonding tool 500 with that of bonding tool 400 described with reference to FIGS. 4A and 4B, downward angle 522 of negative working face segment 520a is equal to downward angle 422 of negative working face segment 420a. Face length 528, however, is greater than face length 428. Such a variation may result in an improved working face configuration.

[0031] Referring now to FIGS. 6A and 6B, bonding tool 600 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 6A, bonding tool 600 is defined by a body portion including cylindrical portion 602, tapered portion 604, and tip portion 606 (i.e., working tip 606). The body portion of bonding tool 600 defines passage 608 that extends from upper end 610 of bonding tool 600 to working tip 606.

[0032] FIG. 6B is a partial cross-sectional enlarged view of working tip 606. Passage 608 (including cylindrical passage 616 and chamfer 612) extends to tip portion 606 of bonding tool 600, tip portion 606 defining working face 620 of bonding tool 600. More specifically, inner chamfer 612 (having inner chamfer diameter 624) of passage 608 terminates at working face 620. A plane P is defined at an intersection I of passage 608 (more specifically, inner chamfer 612 portion of passage 608) and working face 620, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0033] Working face 620 of tip portion 606 includes segment 620a. During engagement with the wire bonding machine, segment 620a directly adjacent the end of passage 608 (more specifically, directly adjacent inner chamfer 612 of passage 608) extends downward (i.e., at downward angle 622) with respect to plane P. Working face segment 620a has a negative face diameter 626 and a face length 628. The remainder of working face 620 directly adjacent segment 620a extends at an upward angle from an end of segment 620a away from the bonding surface (not shown) and toward an outer radius OR of working tip 606. Downward angle 622 of negative working face segment 620a is in a range of about 3 to 30 degrees with respect to plane P. Working face segment 620a comprises a length 628 in a range of about 0.1 to 2.1 mils.

[0034] Comparing the exemplary embodiment of bonding tool 600 with that of bonding tool 400 described with reference to FIGS. 4A and 4B, downward angle 622 of negative working face segment 620a is greater than downward angle 422 of negative working face segment 420a. Face length 628, however, is equal to face length 428 in this example. Such a variation may result in an improved working face configuration.

[0035] Referring to FIGS. 7A and 7B, bonding tool 700 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 7A, bonding tool 700 is defined by a body portion including cylindrical portion 702, tapered portion 704, and tip portion 706 (i.e., working tip 706). The body portion of bonding tool 700 defines passage 708 that extends from upper end 710 of bonding tool 700 to working tip 706.

[0036] FIG. 7B is a partial cross-sectional enlarged view of working tip 706. Passage 708 (including cylindrical passage 716 and chamfer 712) extends to tip portion 706 of bonding tool 700, tip portion 706 defining working face 720 of bonding tool 700. More specifically, inner chamfer 712 (having inner chamfer diameter 724) of passage 708 terminates at working face 720. A plane P is defined at an intersection I of passage 708 (more specifically, inner chamfer 712 portion of passage 708) and working face 720, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0037] Working face 720 of tip portion 706 includes segment 720a. During engagement with the wire bonding machine, segment 720a directly adjacent the end of passage 708 (more specifically, directly adjacent inner chamfer 712 of passage 708) extends downward (i.e., at a downward angle 722) with respect to plane P. Working face segment 720a has a negative face diameter 726 and a face length 728. The remainder of working face 720 directly adjacent segment 720a extends at an upward angle from an end of segment 720a away from the bonding surface (not shown) and toward an outer radius OR of working tip 706. Downward angle 722 of negative working face segment 720a is in a range of about 3 to 30 degrees with respect to plane P. Working face segment 720a comprises a length 728 in a range of about 0.1 to 2.1 mils.

[0038] Comparing the exemplary embodiment of bonding tool 700 with that of bonding tool 400 described with reference to FIGS. 4A and 4B, downward angle 722 of negative working face segment 720a is greater than downward angle 422 of negative working face segment 420a. Similarly, face length 728 is greater than face length 428. Such a variation may result in an improved working face configuration.

[0039] Referring now to FIGS. 8A and 8B, bonding tool 800 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 8A, bonding tool 800 is defined by a body portion including cylindrical portion 802, tapered portion 804, and tip portion 806 (i.e., working tip 806). The body portion of bonding tool 800

defines passage 808 that extends from upper end 810 of bonding tool 800 to working tip 806.

[0040] FIG. 8B is a partial cross-sectional enlarged view of working tip 806. Passage 808 (including cylindrical passage 816 and chamfer 812) extends to tip portion 806 of bonding tool 800, tip portion 806 defining working face 820 of bonding tool 800. More specifically, inner chamfer 812 (having inner chamfer diameter 824) of passage 808 terminates at working face 820. A plane P is defined at an intersection I of passage 808 (more specifically, inner chamfer 812 portion of passage 808) and working face 820, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0041] Working face 820 of tip portion 806 includes a plurality of segments, i.e., segment 820a and 820b. During engagement with the wire bonding machine, segment 820a directly adjacent the end of passage 808 (more specifically, directly adjacent inner chamfer 812) extends downward (i.e., at downward angle 822) with respect to plane P. Working segment 820a has a negative face diameter 826. Another segment 820b of working face 820 directly adjacent segment 820a extends at a downward angle 830 with respect to plane P. Working segment 820b has a negative face diameter 832. Downward angle 822 of negative working face segment 820a is in a range of about 3 to 30 degrees with respect to plane P. Downward angle 830 of negative working face segment 820b is in a range of about 3 to 30 degrees with respect to plane P.

[0042] Referring to FIGS. 9A and 9B, bonding tool 900 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 9A, bonding tool 900 is defined by a body portion including cylindrical portion 902, tapered portion 904, and tip portion 906 (i.e., working tip 906). The body portion of bonding tool 900 defines passage 908 that extends from upper end 910 of bonding tool 900 to working tip 906.

[0043] FIG. 9B is a partial cross-sectional enlarged view of working tip 906. Passage 908 (including cylindrical passage 916 and chamfer 912) extends to tip portion 906 of bonding tool 900, tip portion 906 defining working face 920 of bonding tool 900. More specifically, inner chamfer 912 (having inner chamfer diameter 924) of passage 908 terminates at working face 920. A plane P is defined at an intersection I of passage 908 (more specifically, inner chamfer 912 portion of passage 908) and working face 920, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0044] Working face 920 of tip portion 906 includes a plurality of segments, i.e., segment 920a, 920b, and 920c. During engagement with the wire bonding machine, segment 920a directly adjacent the end of passage 908 (more specifcally, directly adjacent inner chamfer 912) extends downward (i.e., at downward angle 922) with respect to plane P. Working segment 920a has a negative face diameter 926. Another segment 920b of working face 920 directly adjacent segment 920a extends at a downward angle 930 with respect to plane P. Working segment 920b has a negative face diameter 932. A further segment 920c of working face 920 directly adjacent segment 920b extends at an upward angle 934 with respect to plane P. Working segment 920c has a positive face diameter 936.

[0045] Downward angle 922 of negative working face segment 920a is in a range of about 3 to 30 degrees with respect to plane P. Downward angle 930 of negative working face segment 920b is in a range of about 3 to 30 degrees with respect to plane P. Upward angle 934 of positive working face segment 920c is in a range of about 0 to 30 degrees with respect to plane P.

[0046] Referring now to FIGS. 10A and 10B, bonding tool 1000 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 10A, bonding tool 1000 is defined by a body portion including cylindrical portion 1002, tapered portion 1004, and tip portion 1006 (i.e., working tip 1006). The body portion of bonding tool 1000 defines passage 1008 that extends from upper end 1010 of bonding tool 1000 to working tip 1006.

[0047] FIG. 10B is a partial cross-sectional enlarged view of working tip 1006. Passage 1008 (including cylindrical passage 1016 and chamfer 1012) extends to tip portion 1006 of bonding tool 1000, tip portion 1006 defining working face 1020 of bonding tool 1000. More specifically, inner chamfer 1012 (having inner chamfer diameter 1024) of passage 1008 terminates at working face 1020. A plane P is defined at an intersection I of passage 1008 (more specifically, inner chamfer 1012 portion of passage 1008) and working face 1020, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0048] Working face 1020 of tip portion 1006 includes a plurality of segments, i.e., segment 1020a and 1020b. During engagement with the wire bonding machine, segment 1020a directly adjacent the end of passage 1008 (more specifically, directly adjacent inner chamfer 1012) extends downward (i.e., at downward angle 1022) with respect to plane P. Working segment 1020a has a negative face diameter 1026.

Another segment 1020b of working face 1020 directly adjacent segment 1020a extends along a plane substantially parallel to plane P. Downward angle 1022 of negative working face segment 1020a is in a range of about 3 to 30 degrees with respect to plane P.

[0049] Referring to FIGS. 11A and 11B, bonding tool 1100 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 11A, bonding tool 1100 is defined by a body portion including cylindrical portion 1102, tapered portion 1104, and tip portion 1106 (i.e., working tip 1106). The body portion of bonding tool 1100 defines passage 1108 that extends from upper end 1110 of bonding tool 1100 to working tip 1106.

[0050] FIG. 11B is a partial cross-sectional enlarged view of working tip 1106. Passage 1108 (including cylindrical passage 1116 and chamfer 1112) extends to tip portion 1106 of bonding tool 1100, tip portion 1106 defining working face 1120 of bonding tool 1100. More specifically, inner chamfer 1112 (having inner chamfer diameter 1124) of passage 1108 terminates at working face 1120. A plane P is defined at an intersection I of passage 1108 (more specifically, inner chamfer 1112 portion of passage 1108) and working face 1120, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0051] Working face 1120 of tip portion 1106 includes a plurality of segments, i.e., segment 1120a, 1120b, and 1120c. During engagement with the wire bonding machine, segment 1120a directly adjacent the end of passage 1108 (more specifically, directly adjacent inner chamfer 1112) extends downward (i.e., at a downward angle) 1122 with respect to plane P. Working segment 1120a has a negative face diameter 1126. Another segment 1120b of working face 1120 directly adjacent segment 1120a extends at a downward angle 1130 with respect to plane P. Working segment 1120b has a negative face diameter 1132. A further segment 1120c of working face 1120 directly adjacent segment 1120b extends along a plane substantially parallel to plane P. Downward angle 1122 of negative working face segment 1120a is in a range of about 3 to 30 degrees with respect to plane P. Downward angle 1130 of negative working face segment 1120b is in a range of about 3 to 30 degrees with respect to plane P.

[0052] FIG. 12A is a partial block diagram a wire bonding machine in accordance with an exemplary embodiment of the present invention, and FIG. 12B is a detail view of the working tip of the bonding tool of the wire bonding machine of FIG. 12A. The

wire bonding machine includes bonding surface 1242 (e.g., a heat block of the wire bonding machine) configured to support substrate 1224 (e.g., leadframe 1224). Semiconductor die 1240 is mounted on substrate 1224. The wire bonding machine further includes wire spool 1244 that supplies wire 1222 to bonding tool 1200. A body portion of bonding tool 1200 includes cylindrical portion 1202 and tapered portion 1204. The body portion defines passage 1208 configured to receive a length of wire 1222. An end of passage 1208 extends to tip portion 1206 of bonding tool 1200, tip portion 1206 defining a negative working face 1220 (including a length 1236) of bonding tool 1200. Wire 1222a represents a wire loop formed between first ball bond 1238 on semiconductor die 1240 and the second bond on substrate 1224.

[0053] FIG. 12B illustrates the configuration of first ball bond 1238 on semiconductor die 1204, showing that ball bond 1238 covers the entire surface of chamfer 1212 (having a chamfer length 1234), but does not cover the entire surface of negative working face length 1236 of working face 1220. Downward angle 1222 of the portion of working face 1220 denoted by length 1236 is in a range of about 3 to 30 degrees with respect to plane P. The portion of working face 1220 denoted by length 1236 has a negative face diameter 1226, and a negative working face length 1236 in a range of about 0.1 to 2.1 mils.

[0054] Referring now to FIGS. 13A and 13B, bonding tool 1300 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 13A, bonding tool 1300 is defined by a body portion including cylindrical portion 1302, tapered portion 1304, and tip portion 1306 (i.e., working tip 1306). The body portion of bonding tool 1300 defines passage 1308 that extends from upper end 1310 of bonding tool 1300 to working tip 1306.

[0055] FIG. 13B is a partial cross-sectional enlarged view of working tip 1306. Passage 1308 (including cylindrical passage 1316 and chamfer 1312) extends to tip portion 1306 of bonding tool 1300, tip portion 1306 defining working face 1320 of bonding tool 1300. More specifically, inner chamfer 1312 (having inner chamfer diameter 1324) of passage 1308 terminates at working face 1320. A plane P is defined at an intersection I of passage 1308 (more specifically, inner chamfer 1312 portion of passage 1308) and working face 1320, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0056] Working face 1320 of tip portion 1306 includes segment 1320a. Working face segment 1320a comprises a concave shape. During engagement with the wire

bonding machine, segment 1320a directly adjacent the end of passage 1308 (more specifically, directly adjacent inner chamfer 1312 of passage 1308) extends downward with respect to plane P. Working face segment 1320a has a negative face diameter 1326 and a face length 1328. The remainder of working face 1320 directly adjacent segment 1320a extends at an upward angle from an end of segment 1320a away from the bonding surface (not shown) and toward an outer radius OR of working tip 1306. Working face segment 1320a comprises a length 1328 in a range of about 0.1 to 2.1 mils.

[0057] Referring to FIGS. 14A and 14B, bonding tool 1400 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 14A, bonding tool 1400 is defined by a body portion including cylindrical portion 1402, tapered portion 1404, and tip portion 1406 (i.e., working tip 1406). The body portion of bonding tool 1400 defines passage 1408 that extends from upper end 1410 of bonding tool 1400 to working tip 1406.

[0058] FIG. 14B is a partial cross-sectional enlarged view of working tip 1406. Passage 1408 (including cylindrical passage 1416 and chamfer 1412) extends to tip portion 1406 of bonding tool 1400, tip portion 1406 defining working face 1420 of bonding tool 1400. More specifically, inner chamfer 1412 (having inner chamfer diameter 1324) of passage 1408 terminates at working face 1420. A plane P is defined at an intersection I of passage 1408 (more specifically, inner chamfer 1412 portion of passage 1408) and working face 1420, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0059] Working face 1420 of tip portion 1406 includes segment 1420a. Working face segment 1420a comprises a convex shape. During engagement with the wire bonding machine, segment 1420a directly adjacent the end of passage 1408 (more specifically, directly adjacent inner chamfer 1412 of passage 1408) extends downward with respect to plane P. Working face segment 1420a has a negative face diameter 1426 and a face length 1428. The remainder of working face 1420 directly adjacent segment 1420a extends at an upward angle from an end of segment 1420a away from the bonding surface (not shown) and toward an outer radius OR of working tip 1406. Working face segment 1420a comprises a length 1428 in a range of about 0.1 to 2.1 mils.

[0060] Referring now to FIGS. 15A and 15B, bonding tool 1500 is configured for engagement with a wire bonding machine (not shown). As shown in FIG. 15A, bonding

tool 1500 is defined by a body portion including cylindrical portion 1502, tapered portion 1504, and tip portion 1506 (i.e., working tip 1506). The body portion of bonding tool 1500 defines passage 1508 that extends from upper end 1510 of bonding tool 1500 to working tip 1506.

[0061] FIG. 15B is a partial cross-sectional enlarged view of working tip 1506. Passage 1508 (including cylindrical passage 1516 and chamfer 1512) extends to tip portion 1506 of bonding tool 1500, tip portion 1506 defining working face 1520 of bonding tool 1500. More specifically, inner chamfer 1512 (having inner chamfer diameter 1524) of passage 1508 terminates at working face 1520. A plane P is defined at an intersection I1 of passage 1508 (more specifically, inner chamfer 1512 portion of passage 1508) and working face 1520, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0062] The intersections between tip surfaces comprise curved shapes. More specifically, intersections I1 and I2 are curved rather than sharp. Curved shapes may include any type of radius or rounded shape. Alternatively, the intersections may be sharp (as shown in the previous figures), chamfered, or any other suitable shape or geometry.

[0063] Working face 1520 of tip portion 1506 includes segment 1520a. During engagement with the wire bonding machine, segment 1520a directly adjacent the end of passage 1508 (more specifically, directly adjacent inner chamfer 1512 of passage 1508) extends downward (i.e., at a downward angle 1522) with respect to plane P. Working face segment 1520a has a negative face diameter 1526. The remainder of working face 1520 directly adjacent segment 1520a extends at an upward angle from an end of segment 1520a away from the bonding surface and toward an outer radius OR of working tip 1506. Downward angle 1522 of negative working face segment 1520a is in a range of about 3 to 30 degrees with respect to plane P.

[0064] Various exemplary embodiments of the present invention have been described in connection with a segment of the working face of a bonding tool directly adjacent an end of the passage of the bonding tool, where the segment is configured at a negative face angle; however the present invention is not limited thereto. More specifically, the segment directly adjacent the passage may be flat (i.e., substantially planar with a bonding surface), while another segment of the working face is configured at a negative face angle. Referring now to FIGS. 16A-16B, bonding tool 1600 is configured for engagement with a wire bonding machine (not shown). As shown in

FIG. 16A, bonding tool 1600 is defined by a body portion including cylindrical portion 1602, tapered portion 1604, and tip portion 1606 (i.e., working tip 1606). The body portion of bonding tool 1600 defines passage 1608 that extends from upper end 1610 of bonding tool 1600 to working tip 1606.

[0065] FIG. 16B is a partial cross-sectional enlarged view of working tip 1606. Passage 1608 (including cylindrical passage 1616 and chamfer 1612) extends to tip portion 1606 of bonding tool 1600, tip portion 1606 defining working face 1620 of bonding tool 1600. More specifically, inner chamfer 1612 (having inner chamfer diameter 1624) of passage 1608 terminates at working face 1620. A plane P is defined at an intersection I of passage 1608 (more specifically, inner chamfer 1612 portion of passage 1608) and working face 1620, plane P being substantially parallel to a bonding surface (not shown) of the wire bonding machine.

[0066] Working face 1620 of tip portion 1606 includes segments 1620a and 1620b. During engagement with the wire bonding machine, segment 1620a directly adjacent the end of passage 1608 (more specifically, directly adjacent inner chamfer 1612) extends along a plane substantially parallel to plane P. Segment 1620a has a face diameter 1626. Another segment 1620b of working face 1620 directly adjacent segment 1620a extends downward (i.e., at downward angle 1622) with respect to plane P. Working segment 1620b has a negative face diameter 1632. Downward angle 1622 of negative working face segment 1620b is in a range of about 3 to 30 degrees with respect to plane P. Thus, it is clear that the present invention includes embodiments where the segment of the working face directly adjacent the end of the passage is configured at angles other than negative face angles. FIGS. 16A-16B are one example of such an embodiment; however, other combinations of working face segments are contemplated.

[0067] Throughout the various exemplary embodiments of the present invention disclosed herein, a number of negative face angles (e.g., angle 322 in FIG. 3B, angle 422 in FIG. 4B, angles 822 and 830 in FIG. 8B, etc.) are described. Further, a number of positive face angles (e.g., angle 434 in FIG. 4B, etc.) are also described. In general, these angles have been described as falling in a range of between about 0 to 30 degrees, whether positive or negative. It is understood that larger and smaller angles are also contemplated.

[0068] According to an exemplary embodiment of the present invention, the negative face angle (e.g., the downward angle of the segment of the working face

directly adjacent the end of the passage such as angle 322 in FIG. 3B) is at an angle in a range of about 6 to 20 degrees. According to another exemplary embodiment of the present invention, the negative face angle (e.g., the downward angle of the segment of the working face directly adjacent the end of the passage such as angle 322 in FIG. 3B) is at an angle in a range of about 6 to 15 degrees.

[0069] As described herein with respect to certain exemplary embodiments of the present invention, the various segments of the working face of the bonding tool may be in a range of about 0.1 to 2.1 mils. It is understood that larger and smaller segment lengths are also contemplated. The length of these segments (e.g., segments extending downward toward the bonding surface, segments extending upward away from the bonding surface, segments that are substantially parallel with the bonding surface, etc.) may depend upon a number of factors such as, for example, the overall geometry of the working tip of the bonding tool. This geometry includes the width of the working tip, the size of the chamfer diameter, amongst other features. According to another exemplary embodiment of the present invention, the length of the segments is in a range of about 0.2 to 1.9 mils. According to yet another exemplary embodiment of the present invention, the length of the segments is in a range of about 0.2 to 1.2 mils.

[0070] The bonding tool according to the present invention may be formed from a variety of different materials. For example, insulative materials (e.g., alumina, zirconia toughened alumina, etc.); conductive materials (e.g., tungsten carbide, titanium carbide, etc.); and electrically dissipative materials. Further, the bonding tool may be formed from a unitary piece of material, or may be multiple pieces joined together.

[0071] The present invention may be embodied as a method of forming a wire bond and/or a method of forming a wire loop. For example, a method of forming a wire bond may include (1) a step of forming a free air ball, and (2) a step of bonding the free air ball to a bonding location using a bonding tool described herein to form a wire bond. In a method of forming a wire loop, additional steps may be included such as (3) extending a length of wire continuous with the wire bond to another bonding location, and (4) bonding a portion of the wire to the another bonding location to form another wire bond with the bonding tool, thereby forming a wire loop.

[0072] While the present invention has been illustrated with respect to certain exemplary configurations (having a certain number of negative working

segments/faces, positive working segments/faces, and neutral (horizontal) working segments/faces, each of varying angles and lengths), alternative configurations are contemplated.

[0073] Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is Claimed:

1. A bonding tool configured for engagement with a wire bonding machine, the bonding tool comprising:

a body portion, the body portion defining a passage configured to receive a length of wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, wherein during engagement with the wire bonding machine a segment of the working face extends downward with respect to a plane defined at an intersection of the passage and the working face.

2. The bonding tool of claim 1, wherein the segment of the working face is directly adjacent the end of the passage.

3. The bonding tool of claim 1, further comprising another segment of the working face between the end of the passage and the segment.

4. The bonding tool of claim 3, wherein the another segment is substantially parallel to the plane.

5. The bonding tool of claim 1, wherein the segment extends at a downward angle in a range of about 3 to 30 degrees with respect to the plane defined at the intersection of the passage and the working face.

6. The bonding tool of claim 1, wherein the segment extends at a downward angle in a range of about 6 to 20 degrees with respect to the plane defined at the intersection of the passage and the working face.

7. The bonding tool of claim 1, wherein the segment extends at a downward angle in a range of about 6 to 15 degrees with respect to the plane defined at the intersection of the passage and the working face.

8. The bonding tool of claim 1, wherein the segment has a length in a range of about 0.1 to 2.1 mils.

9. The bonding tool of claim 1, wherein the segment has a length in a range of about 0.2 to 1.9 mils.

10. The bonding tool of claim 1, wherein the segment has a length in a range of about 0.2 to 1.2 mils.

11. The bonding tool of claim 1, wherein during engagement with the wire bonding machine the entire working face extends at a downward angle with respect to the plane defined at the intersection of the passage and the working face.

12. The bonding tool of claim 1, wherein another segment of the working face directly adjacent the segment extends at an upward angle with respect to the plane defined at the intersection of the passage and the working face.

13. The bonding tool of claim 1, wherein another segment of the working face directly adjacent the segment extends at a downward angle with respect to the plane defined at the intersection of the passage and the working face.

14. The bonding tool of claim 13, wherein a further segment of the working face directly adjacent the another segment extends at an upward angle with respect to the plane defined at the intersection of the passage and the working face.

15. The bonding tool of claim 13, wherein a further segment of the working face directly adjacent the another segment extends along a plane substantially parallel to the plane defined at the intersection of the passage and the working face.

16. The bonding tool of claim 1, wherein another segment of the working face directly adjacent the segment extends along a plane substantially parallel to the plane defined at the intersection of the passage and the working face.

17. The bonding tool of claim 1, wherein the segment comprises a concave shape.

18. The bonding tool of claim 1, wherein the segment comprises a convex shape.

19. A bonding tool configured for engagement with a wire bonding machine, the bonding tool comprising:

a body portion, the body portion defining a passage configured to receive a length of wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, the working face comprising a plurality of segments, wherein during engagement with the wire bonding machine a segment of the working face directly adjacent the end of the passage extends downward with respect to a plane defined at an intersection of the passage and the working face, and another segment of the working face directly adjacent the segment

extends at an upward angle with respect to the plane defined at the intersection of the passage and the working face.

20. The bonding tool of claim 19, wherein the segment extends at a downward angle in a range of about 3 to 30 degrees with respect to the plane defined at the intersection of the passage and the working face.

21. The bonding tool of claim 19, wherein the segment extends at a downward angle in a range of about 6 to 20 degrees with respect to the plane defined at the intersection of the passage and the working face.

22. The bonding tool of claim 19, wherein the segment extends at a downward angle in a range of about 6 to 15 degrees with respect to the plane defined at the intersection of the passage and the working face.

23. The bonding tool of claim 19, wherein the upward angle is in a range between about 0 and 30 degrees with respect to the plane defined at the intersection of the passage and the working face.

24. The bonding tool of claim 19, wherein the upward angle is in a range of about 6 to 20 degrees with respect to the plane defined at the intersection of the passage and the working face.

25. The bonding tool of claim 19, wherein the upward angle is in a range of about 6 to 15 degrees with respect to the plane defined at the intersection of the passage and the working face.

26. The bonding tool of claim 19, wherein the segment has a length in a range of about 0.1 to 2.1 mils.

27. The bonding tool of claim 19, wherein the segment has a length in a range of about 0.2 to 1.9 mils.

28. The bonding tool of claim 19, wherein the segment has a length in a range of about 0.2 to 1.2 mils.

29. The bonding tool of claim 19, wherein the another segment has a length in a range of about 0.1 to 2.1 mils.

30. The bonding tool of claim 19, wherein the another segment has a length in a range of about 0.2 to 1.9 mils.

31. The bonding tool of claim 19, wherein the another segment has a length in a range of about 0.2 to 1.2 mils.

32. The bonding tool of claim 19, wherein the segment comprises a concave shape.

33. The bonding tool of claim 19, wherein the segment comprises a convex shape.

34. The bonding tool of claim 19, wherein the another segment comprises a concave shape.

35. The bonding tool of claim 19, wherein the another segment comprises a convex shape.

36. A method of forming a wire bond, the method comprising the steps of:

(1) forming a free air ball on an end of a wire extending from a bonding tool; and

(2) bonding the free air ball to a bonding location to form the wire bond using the bonding tool, the bonding tool comprising a body portion, the body portion defining a passage configured to receive a length of the wire, an end of the passage extending to a tip portion of the bonding tool, the tip portion defining a working face of the bonding tool, wherein during bonding a segment of the working face extends downward with respect to a plane defined at an intersection of the passage and the working face.

37. The method of claim 36, wherein the segment of the working face is directly adjacent the end of the passage.

38. The method of claim 36, wherein the bonding tool of step (2) further comprises another segment of the working face between the end of the passage and the segment.

39. The bonding tool of claim 38, wherein the another segment is substantially parallel to the plane.

40. The method of claim 36, wherein the segment extends at a downward angle in a range of about 3 to 30 degrees with respect to the plane defined at the intersection of the passage and the working face.

41. The method of claim 36, wherein the segment of the working face is directly adjacent the end of the passage, and another segment of the working face directly adjacent the segment extends along a plane substantially parallel to the plane defined at the intersection of the passage and the working face.

42. The method of claim 36, wherein the segment of the working face is directly adjacent the end of the passage, and another segment of the working face directly adjacent the segment extends at an upward angle with respect to the plane defined at the intersection of the passage and the working face.

43. The method of claim 36, further comprising the steps of:

(3) extending a length of wire continuous with the wire bond to another bonding location; and

(4) bonding a portion of the wire to the another bonding location to form another wire bond with the bonding tool, thereby forming a wire loop between the bonding location and the another bonding location.