D. Scanning Electron Beam Micro-to-Nano Welding

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Introduction

A method of generating micro-to-nano-scale (50 to 900 nm) welds using a scanning electron microscope's (SEM) electron beam is presented. The energies involved in beam-to-specimen interactions are high enough to melt or drill into metallic samples of small (micro to nano) dimension. This small scale welding method allows for the joining of both micro-electromechanical system (MEMS) and LIGA components as well as joining very fine wire. Micro-to-nano adapted electron beam welding (MAEBW) also mitigates the amount of contamination (which can be especially ruinous at this small scale) found with other processes as the welding takes place within a vacuum atmosphere.

Technical Approach

The electron beam of the SEM can be focused to spot sizes in the nano range (approximately 50-125 nm) and can melt a variety of materials with melt areas ranging from 100 nm to 50 µm. The ability to focus the beam at high magnifications on the faying surface affords reliability and an unparalleled control at this scale. The electron beam can be controlled such that the beam does not raster a large area but traces a pattern on the faying surface to be joined. This is accomplished by decreasing the raster area (increasing the magnification) and by controlling the beam deflection lens currents (raster signal) such that custom signal generation can direct the beam to trace, for example, a helical path allowing for an evenly dispersed heating regime thus avoiding drilling seen in small scale laser welds. The amplitude of the scan area is defined to produce welds commensurate with the part size.

Results and Discussion

Electron beam characterization was the first step in developing a method for using an SEM as a welder. The beam spot size was verified by irradiating a graphite-coated glass slide in the SEM's spot mode. Resultant spot sizes obtained by electron-beam ablation of the graphite coating range from 50 to 125 nm depending on the positioning of the condenser lenses. The glass substrate melts at long spot dwell times (>2 seconds). Average specimen current is approximately 500 nA at an accelerating voltage of 30 kV making the average beam power approximately 15 mW. The average power density of the beam thus ranges from 1.3 to 7.6 MW/mm^2. This power density is commensurate with that of Q-switched short wavelength laser processing where literature values of 200-1000 kW/mm^2 will melt glass and 1-10 MW/mm^2 will melt silicon and metals. A higher specimen current (5,000 nA) can be achieved by the removal of the objective aperture. With the removal of the objective aperture, however, a loss of resolution precludes focusing at a higher magnification on the SEM in question. Successful MAEBW of such materials as polysilicon, nickel, Alumel, Chromel, and Tophet C is accomplished with proper beam control relative to part size where sample sizes range from 500 nm to 50 µm (though bulk samples >50 µm will also be evaluated). Resultant welds are crack free and are not porous. The welds have not shown the spiking or ripple formation typical of conventional macro scale electron beam welding; however, these are not deep partial penetration fusion zones. Heat input is also low enough that distortion of the small parts is avoided and the heat-affected zone is minimized.

Conclusion

We show a method of adapting a scanning electron microscope to welding micro-to-nano scale parts and that many materials of varying geometries (MEMS and LIGA components) can be successfully joined by MAEBW. As a process that provides a clean, consistent method for joining micro-to-nano scale materials, MAEBW is a promising new tool.

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