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(G*) Self-witnessing coherent imaging for artifact removal and noise filtering in laser keyhole welding

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High-power lasers are rapidly becoming standard tools in advanced manufacturing, mainly in the form of laser welding, laser cutting, and laser additive manufacturing. Of these applications, laser welding in the electric mobility sector—particularly in the manufacturing of battery packs—presents unique challenges. Weld depth needs to be precisely controlled, not only to ensure joint strength, but also to ensure the weld does not puncture into the lithium ion cell. In addition, these processes often involve highly reflective metals (such as copper), which have material properties that lead to unstable welds; this requires an unprecedented level of control to ensure weld quality and depth. To better monitor and control weld quality, we need fully in-line monitoring during the process. Inline Coherent Imaging (ICI) is a process monitoring technique that has been demonstrated to measure keyhole depth (down to 15 um axial resolution) at high imaging rates (˜200 kHz), even in high aspect ratio features. Due to its interferometric nature, coherent imaging has unparalleled sensitivity and dynamic range. However, it suffers from speckle noise, which degrades high-speed measurements by orders of magnitude, and false interfaces that arise from unwanted interferences ("autocorrelation"peaks). These pose a significant challenge to quality assurance and closed-loop control, particularly in highly dynamic laser processing applications, such as copper welding. To mitigate these problems, we have integrated a second, automatically synchronized, imaging channel into a standard ICI system, by exploiting a previously unused part of the imaging window. This "witness"image allows us to identify real signatures based on correlation and filter out the uncorrelated noise. Using this system, we have demonstrated the complete removal of autocorrelation artifacts, and have increased signal to noise by a factor of two, with no loss of imaging rate or spatial resolution compared to standard ICI. When applied to imaging laser keyhole welding, the false interface detection rate is reduced from 10% to 0.15%, yielding improved tracking of the true morphology.

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