Direct bonding of semiconductors by through-transmission laser welding

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Ultrafast laser welding is an advanced manufacturing technology capable of bonding materials by selectively irradiating the interface between them. In this process, the beam is focused at the interface through the transparent top material, resulting in melting and subsequent bonding after resolidification (Fig. 1a). This has allowed to weld several materials in different configurations including through-glass, polymers or ceramics. However, it is striking to note that this process remains difficult to apply on silicon (Si) or other semiconductors, which would most certainly benefit the microelectronics industry.

The intrinsic properties of Si (high refractive index and narrow bandgap) impede producing internal modifications by common laser processing configurations since nonlinear propagation effects and prefocal plasma avoid reaching high enough intensities at the focal spot to induce modification. To circumvent these effects, recently the first demonstration of laser welding of silicon on copper was made with picosecond pulses, obtaining relatively modest ~2 MPa bonding strengths [1]. After examining pulse durations from 200 fs up to ~20 ps, we confirm important physical limitations with intense pulses. In view of this, and inspired by stealth dicing in which the thermal properties of nanosecond pulses are used to create below-surface modification for subsequent dicing, we propose to use a similar approach to melt the interface of two Si pieces and join them.

In this work, by disruptively moving to longer pulses of 5 ns at 1550 nm, we present the first demonstration of laser welding of Si. First, by single-spot irradiations (Fig. 1b), we identify that small imperfections in the contact constitute a Fabry-Perot cavity that leads to no modification of the bottom piece. Relying on regions in optical contact, we later vary the irradiations conditions (focus position and scan speed) to determine the most material mixture between wafers without the appearance of detrimental cracks, cavities or porosities. We then raster-scan the optimized beam to produce a large welded area (Fig. 1c). By shear force measurements, we demonstrate a joining strength of 32±10 MPa for the Si-Si configuration. Later, we extend this optimization work to gallium arsenide (GaAs) and test different configurations alongside with Si finding shear joining strengths >10 MPa in all processed cases [2].

To our knowledge, this provides not only the first demonstration of laser welding of similar semiconductors but also dissimilar ones (Si and GaAs). The bonding strengths are similar to those obtained by molecular wafer bonding and ultrafast laser welding of dielectrics, leading to unprecedented process efficiency, given the use of a very compact fiber laser source. To illustrate this, we produced a few millimeters Si-GaAs weld (3.5×7 mm^2), allowing to hang the employed laser equipment (Fig. 1d). We anticipate that the process can be advantageously scaled up to large wafers with the use of industrial high-power sources, holding great potential for a unique additive manufacturing solution applicable to semiconductors.

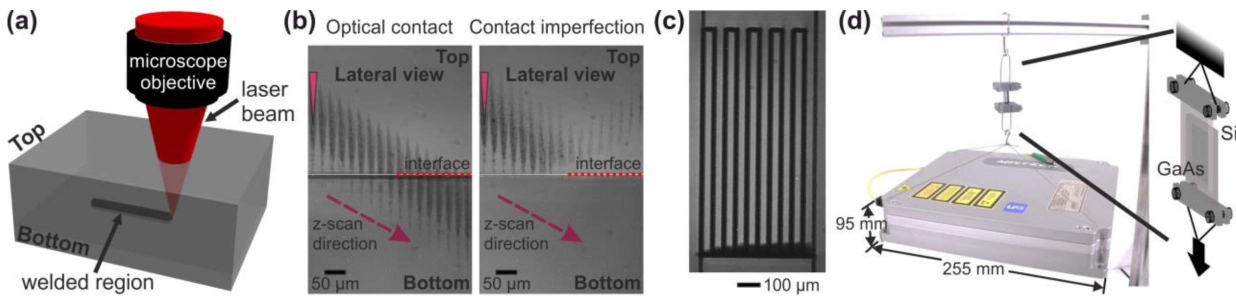

Figure 1 (a) Scheme of the laser welding procedure. (b) Lateral view by IR transmission microscopy of the Si-Si interface. Imperfect contact leads to faulty welding. (c) IR transmission image of a welded serpentine in the Si-GaAs configuration. d) Image of the laser source used in the experiments (~3 kg) hanging from a Si wafer welded on GaAs. A scheme is shown on the right.

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