Fig. 1. At the bottom, the wafer table is depicted. Above that, three identical substrate-holding devices that are attached to a robotic actuator are located. The arrows are pointing to the probe tips of three MEMS chips that have just been separated from the wafer. The separation of the MEMS chips from the wafer is assisted by suction needles that reach through the substrate.

To ensure good understanding of the alignment process, we extensively analyze models and experimental data for solder-induced self-alignment motion reported in the literature. Subsequently, we develop an adapted model that describes the motion we observe in our case study. We find that the alignment motion is dominated by solder-specific effects and, in particular, by the speed of oxide reduction.

II. PARALLEL C4 BONDING

In the C4 process, the substrate and chip have a matching array of solder-bumped contact pads. During the assembly, the chip is flipped upside down and placed at the desired position on the substrate. The solder is liquefied, and bridges the facing pads. When the solder cools down, lasting mechanical and electrical connections are formed [1]. Currently, a parallel C4 process is not feasible since each chip needs to be precisely aligned to the corresponding substrate.[1] The combined use of deterministic and stochastic assembly methods presented in this paper lowers that requirement.

Our process also relies on solder-bump joining. One of its essential features is that the chips are not flipped, however. Instead, they are connected to the substrate when they are already separated from the wafer (by means of dicing or etching) but still located at their original position: A robotic manipulator places several heated substrates above the wafer. The substrates are spaced out at an interval matching the spacing of chips in the wafer or a multiple thereof. As the robotic manipulator lowers the set of substrates, the corresponding pads of substrate and chip are connected through the liquefied solder. The substrate is then lifted, pulling the chips along. Once the chips are free-hanging, the surface forces of the molten solder will work toward minimizing the distance between the matching pads and align the chips (see Fig. 1).

[1]The requirement is not inherent to C4. Rather, it is imposed by the commonly used chuck heating method.
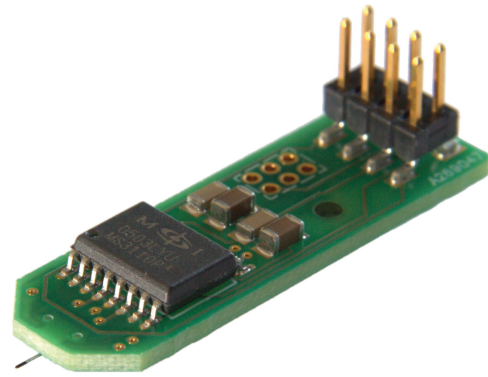

Fig. 2. FemtoTools FTS260 force sensor.

A. Required Robotic Precision

Assuming that the solder bumps form a spherical shape when molten, the maximum placement precision required is half the size of the solder pad diameter. Once the solder wets, surface forces finely align the pads and, thereby, the MEMS chips.

B. Space Saving

MEMS chips typically require very few electrical connections. The individual pads can be larger and more spread out than the ones found on ICs. Since they can be placed freely on the chip, little chip real estate is lost. Because the pads on the substrate are placed underneath the chip rather than around it, the total package size can be reduced compared to wire bonding in most cases.

III. CASE STUDY

The invented method was verified in a case study. A demonstrator was built to bond FemtoTools FTS260 force sensors (see Fig. 2) to substrates. The chip was directly attached (DCA) to an organic substrate. The substrate was an FR-4 printed circuit board (PCB). Apart from the MEMS chip, the PCB additionally contained readout electronics. For the final device to produce accurate measurements, it is essential that the sensor is exactly oriented with the substrate.

The sensor was fabricated from a silicon-on-insulator wafer using reactive ion etching (RIE) and deep reactive ion etching (DRIE) processes [6]. Because the force sensor must directly contact its environment, it did not receive protective packaging. The transducer fabrication process did not require dicing of the wafer. Instead, the device wafer was placed on a support wafer.[2] During the etching process, the individual chips were completely separated from the device wafer. The chips could move freely in a 200 μm gap created by the etching process, and their precise position was no longer defined. The substrate featured square pads with a side length of 380 μm, while the chip featured rectangular pads of 360×400 μm size. The maximum diagonal distance between pads was 3.6 mm.

The force sensor chip converts the force to be measured into a deflection using elastic flexures. The deflection is detected

[2]In the periphery, device and support wafer were connected through a thin layer of heat-conductive paste.