



**Figure 7.18** Illustration of continuous sonocrystallization in a millifluidic device (a) integrating a piezoelectric element for transfer of ultrasound and Peltier elements for removing heat (b). Reprinted with permission from ref. 284. Copyright 2016 American Chemical Society.

ultrasound has a significant effect both on nucleation as well as on crystal growth kinetics. The mean crystal size decreased by a factor of four when ultrasound above a minimum energy threshold of 16 W/L was applied. In addition, the crystal surfaces contained defects and the crystal shape was affected significantly by the ultrasound.

The scale-up of sonocrystallization of manganese carbonate in an MSMPR crystallizer was studied by Gielen *et al.*<sup>290</sup> It was found that the use of a single transducer at larger scale is likely to be ineffective due to the fast dissipation of ultrasound and limited penetration depth.<sup>278</sup> Therefore, it is recommended to design the equipment for sonocrystallization based on multiple transducers. First, the authors tested both a probe and a transducer at lab scale to determine the best performing design. Second, a 50 L MSMPR crystallizer was constructed in which two probes could be placed (2 kW at 24 kHz and 1 kW at 40 kHz). The two probes emitted the ultrasonic field predominantly in different directions (*i.e.*, one in axial direction and one in radial direction) to improve uniformity of the ultrasonic field. They found that a comparable size was obtained under silent and sonicated conditions in contrast to experiments on a smaller scale, which was attributed to attrition in the pump of a recirculation system and the lower power input at larger scale (*i.e.*, 16 W/L at semi-pilot scale compared to 50 W/L on lab-scale). At a larger scale, multiple transducers and radial oscillating probes are better capable of producing an effective ultrasound field. For example, modular flow cells with a height of 1 m each and 40 transducers operating at a maximum power of 50 W have been presented in literature.<sup>278</sup> Despite the growing number of academic studies in the application of ultrasound in continuous settings, reports on the use of ultrasound on an industrial scale are highly limited in the open literature.