“Localized optothermal heating of nanoparticles for DNA melting”

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[Abstract]

Heating and cooling has been the performance bottleneck of Polymerase Chain Reaction (PCR) since its invention about thirty years ago. All approaches so far require time-consuming repetitive heating and cooling of the entire sample. Usually, this is achieved by a heating block or stream of air that causes a heat transport in and out of the sample. However, the poor thermal conductivities of both the PCR solution and the reaction vessel severely limit the effective heating and cooling rates in conventional PCR to <10K/s.

We report on a novel approach for ultrafast DNA melting and its application for PCR. In this technique, after the elongation of primers functionalized onto gold nanoparticles a laser pulse locally heats up the nanoparticles. Thereby, the newly formed DNA double strands are denatured. For this purpose a microsecond optothermal excitation of the nanoparticles causes a localization of the heat field such that only a millionth of the solution is raised to the denaturation temperature. Thus, as soon as the excitation finishes, the thermal energy of the nanoparticles and their close environment is dissipated into the bulk of the solution cooling the nanoparticles to their initial temperature on a nanosecond time scale. This allows for up to one million times shorter PCR temperature ramps in comparison to conventional PCR with its global heating process. As the reaction remains at the productive temperature of the polymerase virtually the entire time, the cycle duration is fundamentally only limited by the processivity of the polymerase.

Surprisingly, it turns out that overcoming the heating and cooling restrictions of conventional PCR leads to a new strategy regarding the design and optimization of PCR protocols.