MEDNARODNA PODIPLOMSKA ŠOLA JOŽEFA STEFANA

JOŽEF STEFAN INTERNATIONAL POSTGRADUATE SCHOOL

ENTANGLED NEMATIC COLLOIDAL DIMERS AND WIRES

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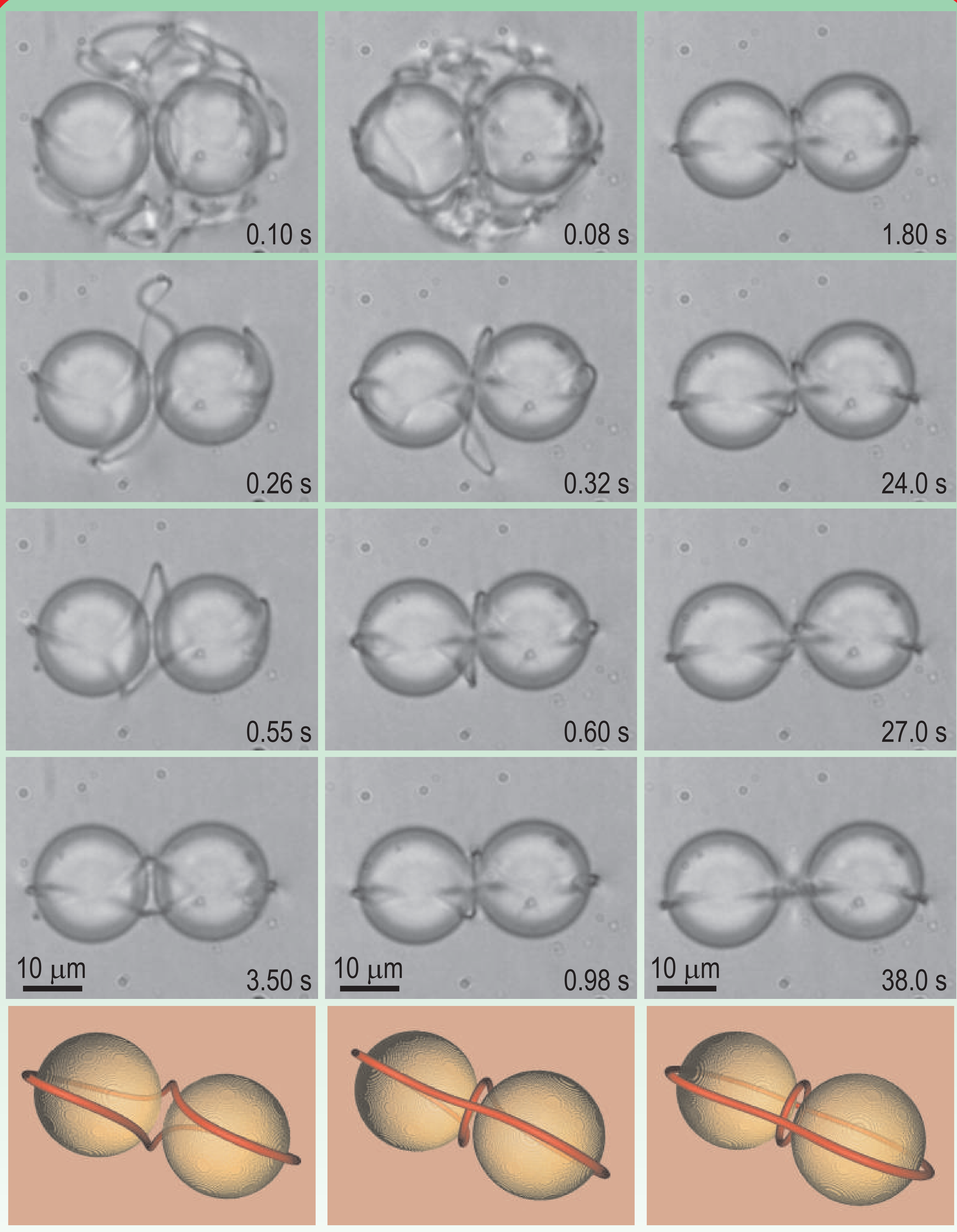
Assembling entangled colloidal pairs by light

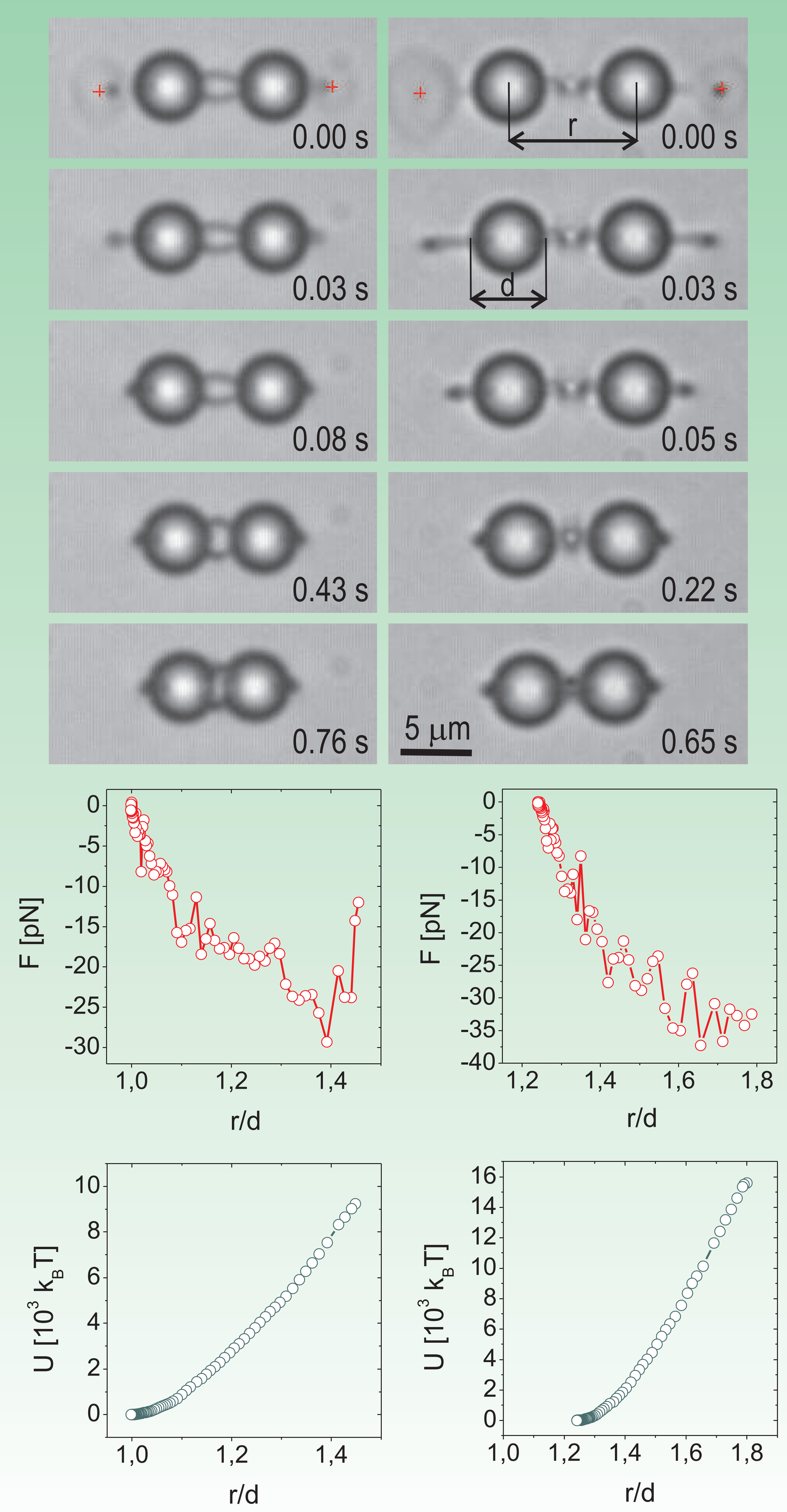
Using focused light of the laser tweezers, the nematic liquid crystal around two colloidal particles was heated into the isotropic phase and then quenched into the nematic phase. The disclination loops are visible under non-polarizing optical microscope due to the scattering of light. Three linear entangled defect structures have been found experimentally, which are topologically equivalent but differ in the way of binding and particle separation.



"figure of eight" | "figure of omega" | "entangled hyperbolic defect"

Stretching and releasing topologicaly bound colloidal pairs by light

The strength of entanglement was measured by switching on two separated light traps. The entangled pair was stretched by moving both traps in the opposite direction and then the light was switched off. The time sequences show that the entangled defect loop acts as a string, pulling both particles together. The effective force and the binding potential are determined from video frames as a function of particle separation r, normalized to the particle diameter d. The measurements were done for the "figure of eight" and the "entangled hyperbolic defect" structure.



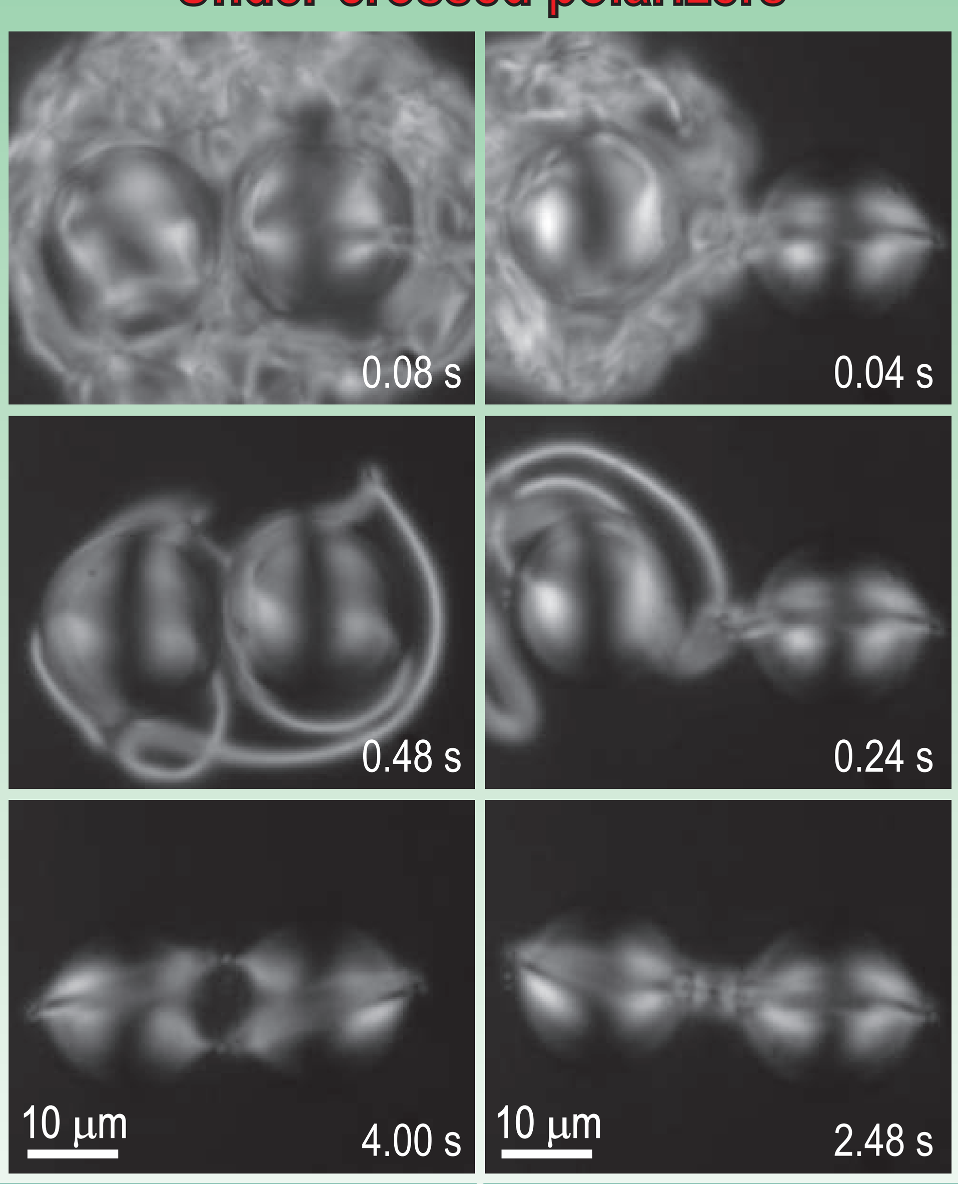
Experimental details

- thin planar cells of thickness from 5 μm to 22 μm were used,
- nematic liquid crystal 5CB was filled inside,
- 4.7 μm and 19 μm diameter glass colloids with homeotropic anchoring at the surface were homogeneously dispersed,
- ITO coating on cell plates enabled quick thermall heating of liquid crystal by high intensity laser beam,
- type of entanglement is unpredictable but procedure is variable and easily repeatable,
- "figure of omega" is unstable configuration and transforms slowly into "entangled hyperbolic defect".

Statistics of the occurrence of entangled colloidal states

124 separate laser tweezers experiments performed on 19 μm microspheres	
48 %	isolated Saturn ring
36 %	"figure of eight"
13 %	"figure of omega"
3 %	"entangled hyperbolic defect"

Under crossed polarizers



"figure of eight" | "entangled hyperbolic defect"

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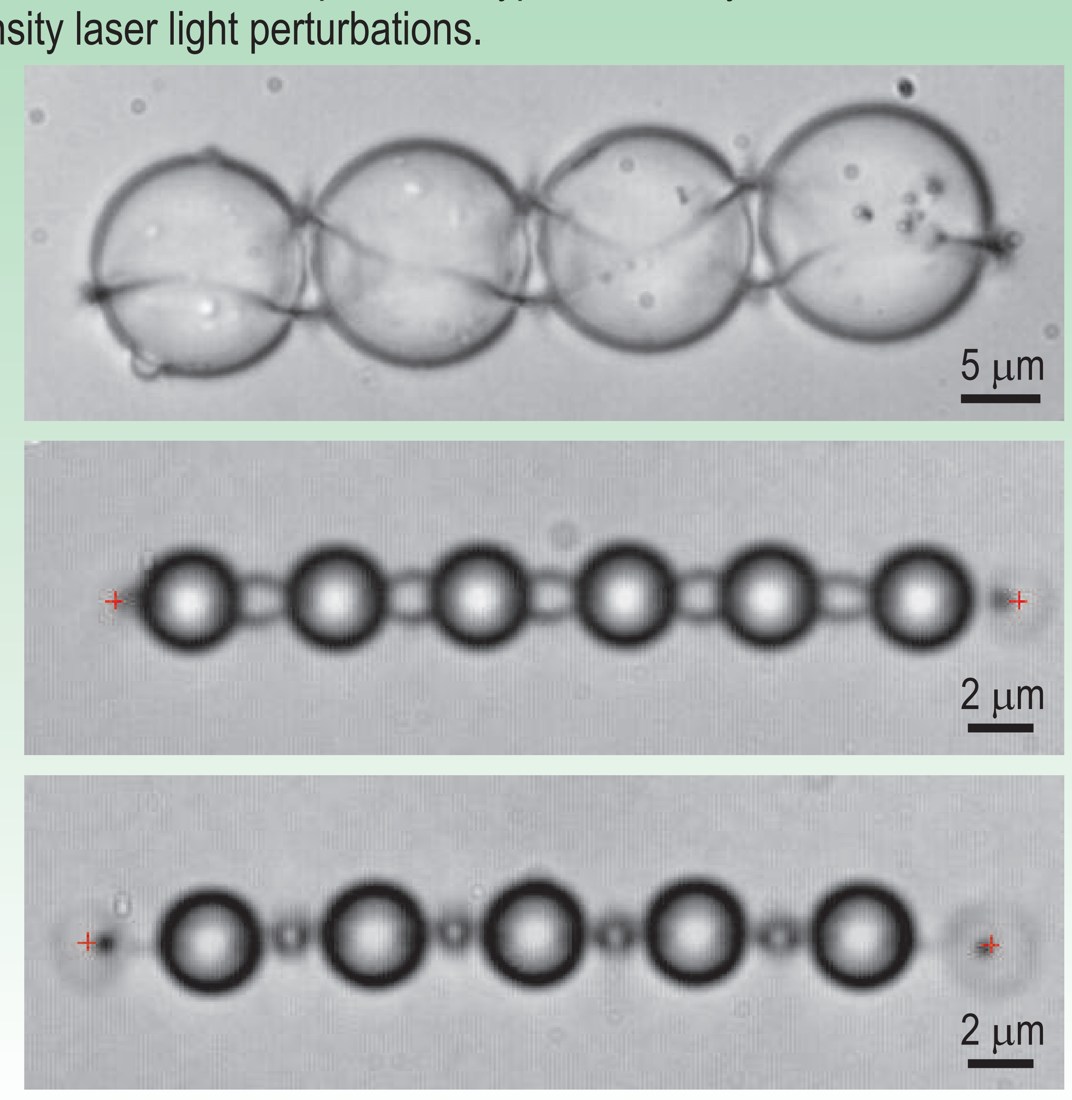
Colloidal wires assembled by entanglement

Colloidal wire resembles a simple nematic braid, where defect lines are winding along colloidal particles. "Figure of eight" colloidal wire is a chiral object, as the twist could be left- or right-handed. The "entangled hyperbolic defect" structure is non-chiral, as it is formed by two orthogonal, disconnected -1/2 defect loops. Both types are very stable and robust to low intensity laser light perturbations.

IPSCS 2009



Conclusion

There are three important aspects of our work:

- we report a novel and unique mechanism of colloidal binding. The formation of entangled defect loops is ultimately connected to the symmetry breaking of the nematic orientational field across the isotropic-nematic phase transition.
- we can study the entanglement in topologically non-trivial systems in real time and at micrometer scale.
- the observed strong binding of colloidal particles opens exciting routes to possible applications. One could construct colloidal wires for electric charge transport, optical wave-guide resonator and even chiral topological defect lines that could be filled up with electro- and opto-responsive nanoparticles.

References

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