Guiding Invisible Light by Plasmonic Resonant Solitons in Metallic Nanosuspensions

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Abstract:

We demonstrate the guiding of invisible light by visible light in plasmonic nanosuspensions. A low-power (40-60 mW) visible green laser beam (532 nm) penetrates through a colloidal suspension of gold spheres by nonlinear self-trapping (optical soliton), which creates a waveguide that allows guidance of an invisible infrared laser beam (1064 nm) of different power levels (20-500 mW). Although the infrared beam itself has very weak or no nonlinear self-action, the green beam undergoes self-trapping at an even lower power due to the presence of and interaction with the infrared beam.

What is going on here?

A lone infrared laser beam (1064 nm) is unable to penetrate a 40 mm sample containing a metallic nanosuspension of gold spheres (D=40 nm). The beam heavily diffracted, allowing no coherent transmission of energy or information.

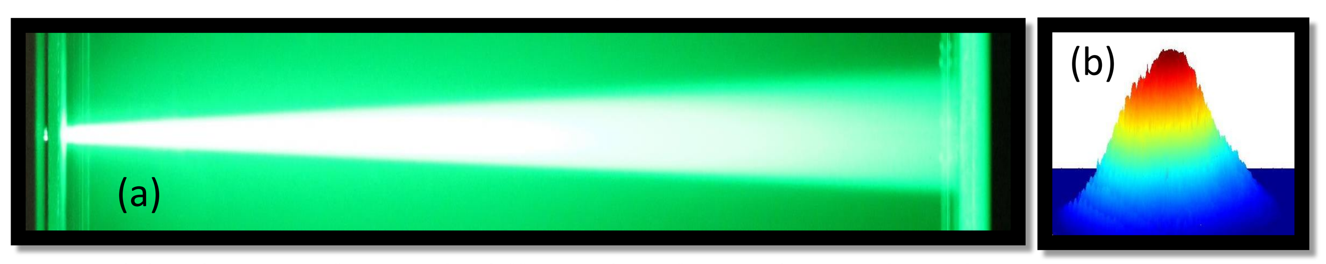


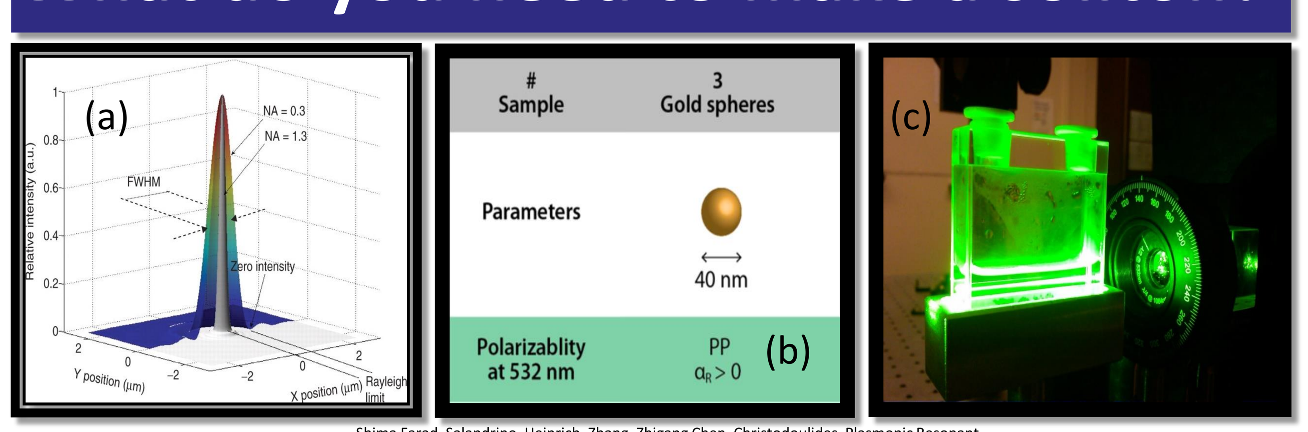
Fig. 1. (a) Side view of severely diffracted, unfocused green laser beam as it propagates through nanosuspension sample, diffracted infrared is identical. (b) Gaussian intensity profile at the output. It is unfocused and spread out, indicating an undesirable spread of beam intensity.

How to solve the problem of diffraction, create a waveguide with a soliton!

A green laser beam is able to create a waveguide (similar to fiber optics) with the metallic nanoparticles by means of a soliton. The soliton takes advantage of the non-linear properties of the laser beam and metallic nanosuspension, and collects the particles in the beam, in effect, creating a "lens" that focuses the beam in each step through the glass cuvette.

Fig. 2. Two examples of how light propagates through fiber optics.

What do you need to make a soliton?



Shima Farad, Salandrino, Heinrich, Zhang, Zhigang Chen, Christodoulides, Plasmonic Resonant Solitons in Metallic Nanosuspensions (Nano Letters ACS Publications March 24, 2014)

Fig. 3. To Create a soliton we need a Gaussian laser beam of adjustable power, metallic nanosuspension, and proper optical set up, including glass cuvette. (a) Gaussian distribution of cross section of laser beam intensity. (b) Metallic nanoparticle used in this experiment. Gold spheres of diameter 40 nm. As a comparison, a human red blood cell has a diameter of roughly 6000 nm. A silicon Atom has a diameter of roughly 0.3 nm. (c) Image of class cuvette that contains the metallic nanosuspension.

How does a soliton work? How does light move metallic nanoparticles? Answer: Gradient Forces!

A soliton is a non-linear wave that propagates with minimal diffraction through any linear or non-linear medium.

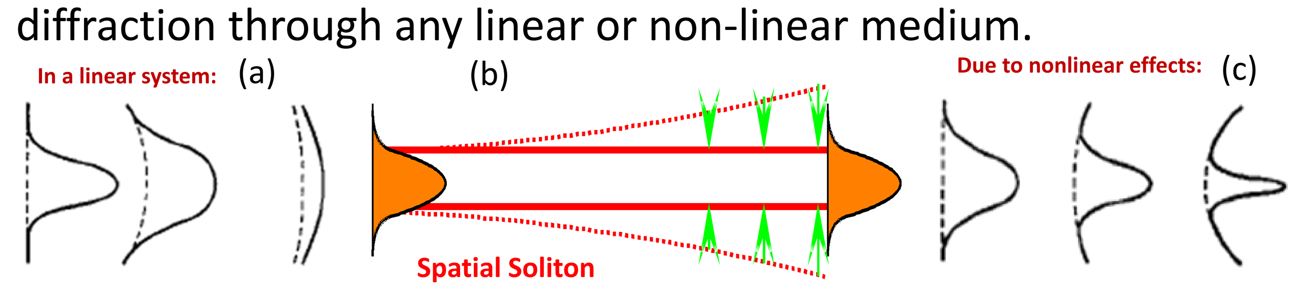


Fig. 4. (a) Diffracting wave front in linear system. (b) Self focused spatial soliton. (c) Self focusing wave front due to non-linear effects.

As a Gaussian laser beam at a resonant wavelength comes into contact with the nanoparticles, a change in the index of refraction and the beam's intensity gradient allows a gradient force to be imparted on the particles, causing them to be attracted or repelled to the beam, depending on their "polarizability". Our gold particles are attracted to the beam, which creates a "lens", and allows the formation of a soliton. The soliton keeps the nanoparticles in the beam down the whole length of the cuvette, focusing the beam.

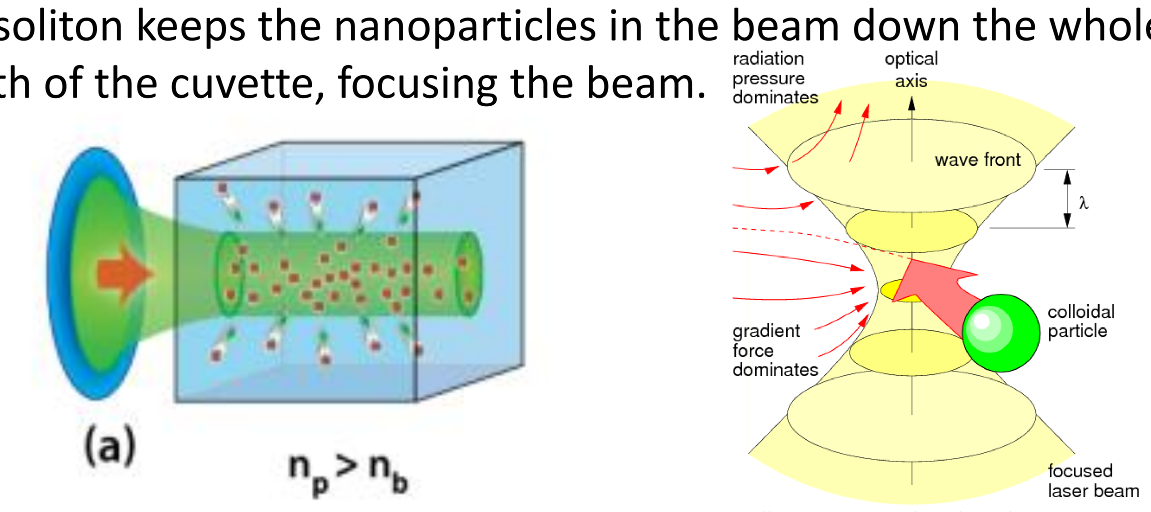


Fig. 5. (a) negatively polarized particles being attracted to beam. (b) Gradient forces acting on nanoparticle.

Experimental Set up

Why are waveguides, solitons and nanoparticles important?

In telecommunications the soliton concept is used for fiber optics and pulse compression. Solitons in nanosuspensions aid in the exploration of the light/matter interaction of nanoparticles, and are applied in optofluidic systems (micro-sized optical systems using fluids). Nanoparticles are actively used in the medical field (ex. to treat and study cancer [1], physical therapies).

Results: Green Plasmonic Resonant Soliton (self focusing)

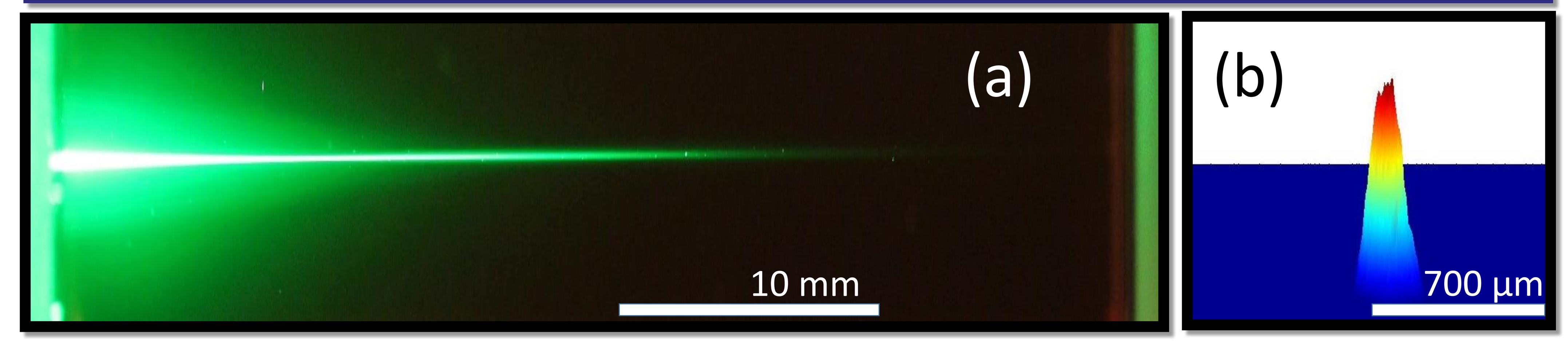


Fig 6. (a) The Green laser beam 60 mW interacts with the gold Nano spheres and creates a soliton which allows self focusing. Above is a side view image of the green laser beam propagating through the 40 mm metallic nanoparticle solution. (a) The Gaussian profile of the beam's output intensity.

No Guidance of Infrared by itself

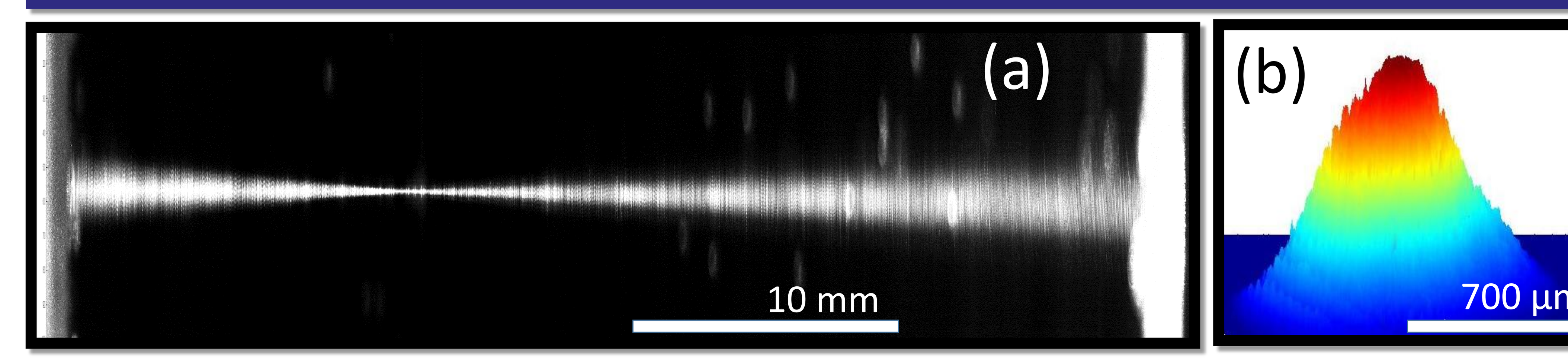


Fig 7. (a) Above is a side view of the unguided Infrared laser beam 50 mW. (b) The Gaussian is not sharp which corresponds to a diffuse output intensity.

Guidance of Infrared by Green

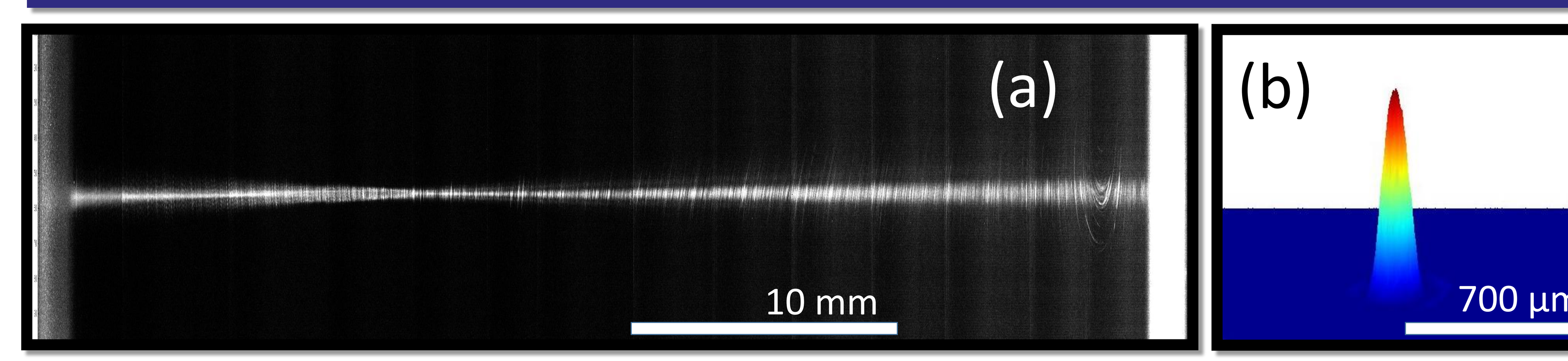


Fig 8. (a) Above is a side view of the Infrared laser beam 50 mW being guided by the green beam 40 mW, image is in infrared only (green cannot be seen). (b) The Gaussian of the output is sharp and focused..

Enhanced Guidance

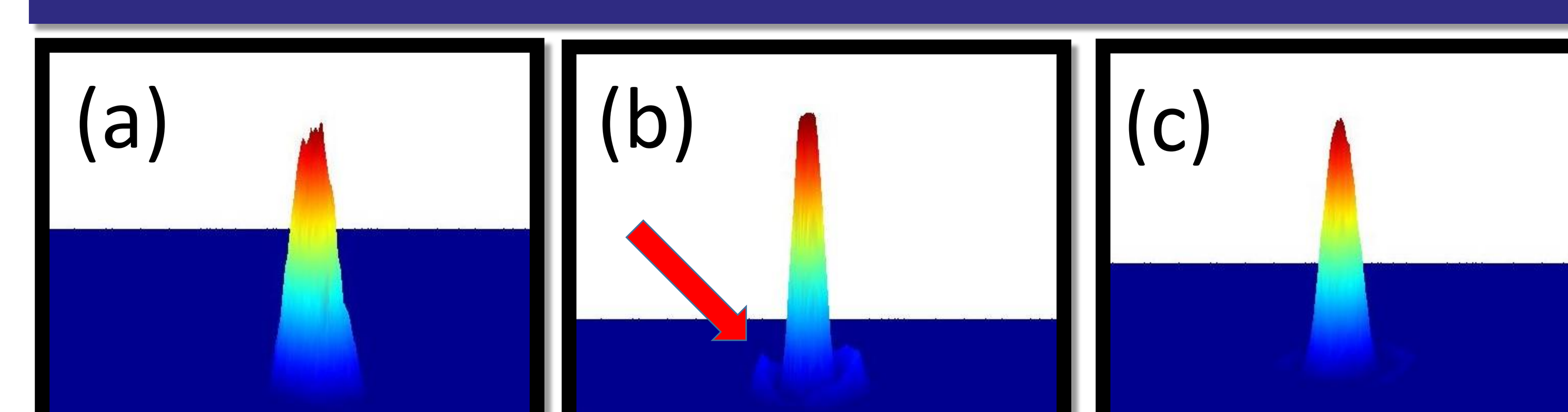


Fig. 9. (a) Green at 60 mW creates a sharp soliton. (b) Green at 60 mW and infrared at 50 mW becomes less focused, resembling sinc(x) function profile. (c) Green 40 mW and IR 50 mW, the infrared helps the green create a soliton at lower

Conclusion

We have effectively shown that one wavelength of light can be guided by another through metallic nanosuspensions. This can open up applications to transportation of information and exploration of nanoparticles interaction with light.

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[1] Wei Lu, Chiyi Xiong, Guodong Zhang, Qiam Huang, Rui Zhang, Jin Z. Zhang, Chun Li Targeted Photothermal ablation of murine melanomas with melanocyte-stimulating hormone analog conjugated hollow gold nano spheres.