Hierarchical information retrieval on employing optical near field technology

An important outcome of optical near field interactions is the ability of various interaction scenarios to behave differently at different scales, known as hierarchy. This inherent hierarchy throws open plethora of hierarchical nanophotonic architectures, yet another innovative application devised by Ohtsu research group. This lecture purports to information retrieval using the principle of optical near fields at various physical scales.

1 Model for hierarchical information retrieval

In the far field, various optical elements such as diffractive optical elements, glass components, holograms etc., rely on their optical responses in the far field. Contrary to this, due to optical near field interaction, nanostructures exist in the above mentioned optical elements, provided that they do not disrupt the optical responses in the far field. Thus by maintaining the original optical response in the far field , one can design nanostructures that are accessibly only through optical near fields. Such nanostructures have the ability to access additional or hidden watermark information to be recorded in the corresponding optical elements.

Ohtsu research group have described the underlying physical model of hierarchy as follows: let a probe that is modeled by a sphere of radius r_p be placed in the proximity of a sample that is modeled by a sphere of radius r_s. When this system is illuminated with an incident light having electric field $\mathbf{E}_0$, electric dipole moments are induced in the system comprising of the probe and the sample, with the dipole moment of the probe, $\mathbf{p}_p = \alpha_p \mathbf{E}_0$ and that of the sample being $\mathbf{p}_s = \alpha_s \mathbf{E}_0$. The electric dipole moment $\mathbf{p}_s$ included in the sample generates an electric field which inturn changes the dipole electric moment in the probe by an amount of say $\Delta\mathbf{p}_p = \Delta\alpha_p \mathbf{E}_0$ and vice versa by an amount $\Delta\mathbf{p}_s = \Delta\alpha_s \mathbf{E}_0$. This results in dipole-dipole interactions. The scattered intensity I induced by the above mentioned dipole moments can be written as

$$\begin{aligned} I &= |\mathbf{p}_p + \Delta\mathbf{p}_p + \mathbf{p}_s + \Delta\mathbf{p}_s|^2, \\ &\approx (\alpha_p + \alpha_s)^2 |E_0|^2 + 4\Delta\alpha(\alpha_p + \alpha_s)|E_0|^2, \end{aligned} \tag{1.1}$$

where one has considered $\Delta\alpha_s = \Delta\alpha_p = \Delta\alpha$. The term $4\Delta\alpha(\alpha_p + \alpha_s)|E_0|^2$ represents the scattered light intensity due to the interaction between the various dipoles.

Ohtsu research group identified the above mentioned scattered light intensity as that containing the relevant information which is the relative difference between sample and the probe. Also $(\alpha_p + \alpha_s)^2 |E_0|^2$ is the background signal for measurement. Thus one can devise a signal contrast by taking the ratio

$$S_c = \frac{4\Delta\alpha}{(\alpha_p + \alpha_s)}. \tag{1.2}$$

Also

$$S_{c_{max}} = S_c|_{r_p = r_s}. \tag{1.3}$$

With this, Ohtsu research group were able to formulate a scale dependant physical hierarchy. From this setup, it is clear that smaller probe can provide a much better resolution than a larger probe. The highlight is that a large diameter probe, even though having only less resolving power, has the capability of detecting certain features that are associated with its scale, a feat not achievable by nanophotonic devices in the far field due to diffraction limit.

2 Principle of operation

In a nanometric subsystem consisting of N nanoparticles lying distributed in a region of sub wavelength scale, the size of the nanoparticles can be nicely resolved on employing a scanning near field microscope, when the size of its probe tip is comparable to the size of the individual nanoparticles. Thus, one can perceive a first layer information where one can retrieve information that is associated with each distribution of nanoparticles corresponding to 2^N different codes. One can further associate a second layer information corresponding to $(N+1)$ different codes when the size of the probe tip is much larger compared to the individual size of the nanoparticles. Thus, by manipulating the scale of observation, one can retrieve different sets of signals. Hence by devising an appropriate coding strategy, one can achieve hierarchical data retrieval by associating the information hierarchically with the distribution and the number of nanoparticles.

3 Experimental demonstration

Ohtsu research group considered a nanometric system comprising of an array of Au nanoparticles each having a diameter in and around $80nm$. This nanometric subsystem was distributed over a SiO_2 substrate within a circular region of radius $200nm$. The array of Au nanoparticle separated by a distance of $2\mu m$ were fabricated by the Ohtsu research group by employing a lit off technique using electron beam lithography with a Cr buffer layer. The above mentioned nanometric subsystem was illuminated by a laser diode at an operating wavelength of $680nm$ and the scattered light was collected by using a near field scanning optical microscope having a large diameter aperture metallic fiber probe. The distance between the substrate and the probe was fixed at $750nm$. Thus Ohtsu research group were successful in retrieving second layer information, thereby validating hierarchical memory retrieval from nanostructures.

4 Additional reading and references

1. M. Ohtsu, K. Kobayashi, T. Kawazoe and T. Yatsui, Principles of Nanophotonics (CRC Press, New York, 2008).

2. M. Ohtsu (Ed.), Progress in Nanophotonics 1 (Springer-Verlag, Berlin, 2011).

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