Applications of optical near field technology in information security

Information security, being a key issue nowadays, demands a robust theory. This lecture deals with three different methods of providing information security using optical near field technology, namely (i) hierarchical holography, (ii) product authentication or certification and (iii) traceability in information processing systems. These novel techniques were devised by the Ohtsu research group.

1 Information retrieval using hierarchical hologram

Conventional anti-counterfeiting techniques that are based on the physical appearance of holograms are not robust against tampering. Hierarchical holography devised by the Ohtsu research group is a novel process used for generating natural three-dimensional images commonly used for anti-counterfeiting techniques.

1.1 Principle of operation of hierarchical holograph

Hierarchical holography utilizes both far field and optical near field operation. However, in the former, being associated with conventional holographic images that are not secure, robust security is not guaranteed. The latter employs optical intensity distribution within a nanometric system which can be obtained only through optical near field interaction, thereby ensuing robust security. This is due to the fact that the optical response of the elements that are mainly governed by propagating light are not influenced by any structured change present in the sub wavelength scale. Thus the visual aspect of the hologram remains intact. Hence by properly manoeuvering structural changes in the sub wavelength region, additional data can be written and thereby adding new functions to conventional holograms. Ohtsu research group have embedded nanophotonic codes that are basically sub wavelength scaled and shape engineered metal nanostructures defined by induced optical near fields.

1.2 Experimental demonstration

Ohtsu research group fabricated a sample device structure of sides $15mm \times 20mm$ on employing electron beam lithography on a *Si* substrate and therein by sputtering a $50nm$ thick *Au* layer. In order that the information be available only by using optical near field interactions, Ohtsu research group slightly changed the shape of the nanostructure and detected the optical responses using a nearfield optical microscope. The nearfield probe tip had a radius of curvature of $5mm$. By connecting the fiber probe to a tuning fork and by sensing a shear force with the tuning fork, the position of the probe was finely regulated. The observation distance, where the optical nearfield was generated between the probe tip and the sample device, was maintained below $50nm$. The nanometric system was then illuminated with a laser diode operating at a wavelength of $785nm$. The incoming light was linearly polarized by passing through a Glan- Thompson polarizer, which was rotated via a half wave plate. The ensuing scattered light was finally detected by a photomultiplier tube. Ohtsu research group obtained different shapes of near field optical microscope images of the nanophotonic codes. They observed clear polarization dependence when the nanophotonic codes were embedded in the hologram and thereby facilitated the retrieval of near field information. As the embedding of a nanophotonic code and its subsequent retrieval involves high technicalities, one can have full proof anti-counterfeiting measures.

2 Authentication function based on nearfield processes

Product authentication or certification is a key issue of information security. This is analogous to a lock and key system where the working of a system to exhibit far field interaction is guaranteed only when their shapes are configured appropriately and when they are closely stacked.

2.1 Principle of operation

In order to study the geometry of a given nanostructure, one has to understand that structure in terms of its individual element and layout factors. The study of individual elements can be obtained from their shapes. The study of various layout factors can be understood from their spatial arrangement. The above mentioned studies can be performed by analyzing the optical response functions of the nanometric systems. When the nanometric system is illuminated with incident light, electric currents are induced between individual optical elements of the metal nanostructure.

In addition to this, optical near fields are also included between the same optical elements. The above mentioned processes can be constituted as vectorial elements in the system. The principle of operation can be underlined as follows: let a nanostructure system comprising of two metal nanostructures be labeled as *typeA* and *typeB*. The above mentioned shapes can be designed as rectangular units on an arbitrary $X-Y$ plane at constant intervals. Let their horizontal sides be aligned along the X-axis and their vertical sides along the Y-axis.

When *typeA* is illuminated with horizontally polarized light, oscillating surface charges accumulate at the horizontal edges of each of the rectangular units. The oscillating surface charges have a phase difference of π. An interesting point to note is that the vertical component of the far field radiation is found to be small externally. This can be attributed to the fact that regarding the vertical component of the far field radiation, *typeA* nanostruture behaves as a quadrupole. Also in *typeA* nanostructure, the near field components are present only in the vicinity of the rectangular units. At this style, let the *typeB* nanostructure is placed on top of the *typeA* nanostructure. One can see that surface charges will be included on the *typeB* nanostrucutre via optical near fields. Finally, the stacked structure of *typeA* and *typeB* nanostructures behave as a dipole. In other words, both the nanostructures allow far field radiation only when they are stacked properly. Thus shape engineered nanostructures and their associated optical near fields initiate a transformation from quadrupole nature to that of dipole nature.

2.2 Experimental demonstration

Ohtsu research group devised a nanometric system such that *typeA* only nanostructures were fabricated in the first layer and *typeB* nanostructures were fabricated in the second layer. On the other hand, the stacked nanostructures had *typeA* nanostructures in the first layer and *typeB* nanostructures in the second layer. Moreover, the stacked structure was fabricated as a single sample. The gap between *typeA* and *typeB* nanostructures was fixed at 200*nm*. When the above mentioned structures were irradiated with horizontally polarized light with a laser diode with an operating wavelength of 690*nm*, the following results were obtained: the *typeA* only nanostructure had an induced surface charge density distribution having a local maximum and a local minimum. The *typeB* only nanostructure did not experience any far field radiation. When the *typeB* nanostructure was stacked on top of the *typeA* nanostructure, the far field radiation increased rapidly due to the transformation from a quadrupole to dipole. In other words, output signal appears only when the *typeA* nanostructure and the *typeB* nanostructure are properly stacked. Thus optical near fields ensure product authentication or certification.

3 Traceability using optical near fields

In information processing systems, security against tampering, ensuring confidentiality with regard to optical memory, managing digital content and privacy protection should be guaranteed. Conventional signal processing systems fail miserably in this regard. This lecture purports to traceability in information processing systems.

3.1 Principle of operation

Shape engineered metal nanostructures exhibit hierarchical features since different physical scales can be attributed to different functions, thereby allowing hierarchical nanophotonic architectures, which leads to hierarchical information retrieval. When one of the hierarchical layers is associated with information dissipation process, the finer scale can be used for implementing traceability.

Ohtsu research group considered a two layer system such that at the smaller physical scale called scale *A*, the system exhibits a unique response. At the large physical scale called scale *B*, the system should output two different signals. This finally boils down to the fact that ad digital output can be retrievable by observing scattering of the incident light from scale *B*.

3.2 Experimental demonstration

Two shape engineered nanostructures were considered, one that had two triangular *Au* metal plates aligned in the same direction named as shape *A* and the other named as shape *B* which had the two triangular plates facing each other. The gap between the two triangular plates was 50*nm*. The horizontal length of one of the triangular plates was 173*nm*, with the angle at its apex at 30° and having a thickness of 30*nm*. The nanometric system was illuminated with incident uniform plane wave operating at the wavelength of 680*nm*. It was observed that the phases of the horizontal component of the electric field inside the *Au* metal were out of phase by 180° between the apex side and the opposite side. Thus for shape *A*, the system can be approximated by two dipoles oriented in the same direction and in the opposite direction for shape *B*. As a result shape *A* behaved effectively as a dipole and shape *B* behaved as a quadruple. Ohtsu research group observed that optical access to a given memory was automatically recorded due to energy dissipation occurring locally at scale *A*. At the same time information was secured at scale *B* based on its behaviour.

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).