Chapter 6 – Conclusion and Future Work

6.1 Conclusion

An innovative double-corrugated C-aperture was proposed and successfully demonstrated by simulations and experiments. The combination of the corrugation and the single-ridge-like nano-waveguide, which signifies the hybrid of the surface plasmon coupling effect and the propagation mode, stands for a dual applicability in data storage system and biosensor engineering. Such a nano-aperture design transcends over the conventional concept and extends its feasibility to another applied technology.

The physical mechanisms that lead to unusual transmission through the C-aperture, the funnel effect and the existence of the propagation mode, were derived by analyzing its power throughput as functions of its dimensions. Another remarkable contribution lies in the linear scale down effect and the invariance of the correspondence relation, greatly facilitating to design a C-aperture that possesses adequate power throughput on arbitrary dielectric substrates. In this phase, the power throughput is enhanced by a factor of $\sim 10^4$ in comparison with a 60*60 nm^2 square aperture at a comparable spot size.

As the grooves were introduced, the physical meanings corresponding to its parameters are deduced by quantum mechanics and solid state physics. The incident-side groove can conduce to a further field enhancement by a factor of 3.84 so that, compared to a 60*60 nm^2 square aperture, an enhancement with $\sim 10^5$ in power throughput is obtained. Furthermore, the exit-side groove will change the field distribution of the emitted light and can diminish the spot size by 44 nm accordingly.

Experiments were also carried out to demonstrate the calculation and analyses. Employing FIB with critical dimension of 100 nm, the apertures can be re-produced well. The near-field field distribution was scanned by an NSOM. While the transmitted energy of the circular aperture was obscured by the background noise, the C-aperture yields a signal-noise-ratio up to 40 dB, indicating the strong near-field enhancement. Exploiting FTMS, the far-field transmission enhancements of 17.8 and 33.0 were obtained, demonstrating the propagation mode of the C-aperture and the surface plasmon polariton coupling effect by the groove, respectively. These experimental results qualitatively agreed with the calculation, suggesting both the academic value and practical utility of this aperture design.

6.2 Future works

The core in the future works is the integrated case. The simulation will proceed to the C-aperture with the surface corrugations on the fiber tip. The experiment of the C-aperture on a slanting end face of a fiber will be implemented in the near future. If the simulated power throughput is further enhanced by the surface corrugation applied on the fiber, it will be also fabricated to demonstrate the calculation. Nevertheless, the fiber-based light delivery module, especially the integrated case, is attempted to realize the hybrid recording, as shown in Fig. 6.2-1.

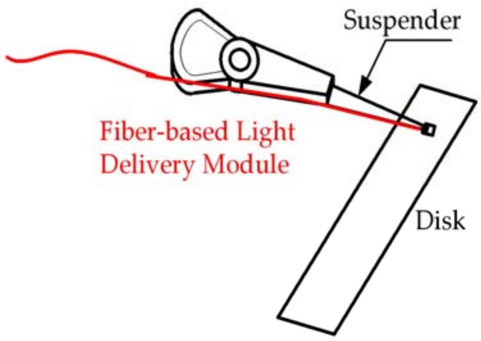

Fig. 6.2-1 Fiber-based light delivery module in realization of hybrid recording

Reference:

[1] S. M. Mansfield and G. S. Kino, “Solid immersion microscope,” Appl. Phys. Lett., Vol. 57, P. 2615 (1990)

[2] E. Betzig, J. K. Trautman, R. Wolfe, E. M. Gyorgy, P. L. Finn, M. H. Kryder, and C.-H. Chang, “Near-field magneto-optics and high density data storage,” Appl. Phys. Lett., Vol. 61, P. 142 (1992)

[3] J. A. Stratton, *Electromagnetic Theory*, New York, McGraw-Hill (1941)

[4] J. D. Jackson, *Electrodynamics*, New York, Wiley (1999)

[5] A. E. H. Love, A treatise on the mathematical theory of elasticity, New York, Dover (1944)

[6] C. J. Bouwkamp, ‘‘Diffraction theory,’’ Rep. Prog. Phys. Vol. 18, P. 35 (1954).

[7] Y. Leviatan, “Study of near-zone fields of a small aperture,” J. Appl. Phys. Vol. 60 P. 1577 (1986)

[8] K. S. Yee, ”Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media,” IEEE Trans. Antennas and Prop., Vol. 14, P. 302 (1966)

[9] A. Taflove and S. C. Hagness, *Computational Electrodynamics*, Boston, Artech House (2000)

[10] K. S. Kunz and R. J. Luebbers, The Finite Difference Time Domain Method for Electromagnetics, Boca Raton, CRC Press (1993)

[11] A. Taflove, *Advances in Computational Electrodynamics*, Boston, Artech House (2001)

[12] H. Raether, Surface Plasmons on Smooth and Rough Surfaces and on Gratings, Berlin, Springer-Verlag (1998)

[13] S. Kawata, Near-Field Optics and Surface Plasmon Polaritons, Berlin, Springer-Verlag (2000)

[14] V. M. Agranovich and D. L. Mills, *Surface Polaritons: Electromagnetic Waves at Surfaces and Interfaces*, Amsterdam, North-Holland, (1982)

[15] S. A. Darmanyan and A. V. Zayats, "Light tunneling via resonant surface plasmon polariton states and the enhanced transmission of periodically nano-structured metal films: An analytical study," Phys. Rev. B, Vol. 67, P. 035424 (2003)

[16] D. Gerard, L. Salomon, F. D. Fornel and A. V. Zayats, "Ridge-enhanced optical transmission through a continuous metal film," Phys. Rev. B, Vol. 69, P. 113405 (2004)

[17] S. A. Darmanyan, M. Neviere, A. V. Zayats, "Analytical theory of optical transmission through periodically structured metal films via tunnel-coupled surface polariton modes," Phys. Rev. B, Vol. 70, P. 075103 (2004)

[18] K. Tanaka, T. Ohkubo, M. Oumi, Y. Mitsuoka, K. Nakajima, H, Hosaka, and K. Itao, "Numerical simulation on read-out characteristics of the planar aperture-mounted head with a minute scatterer," Jpn. J. Appl. Phys., Vol. 40, P. 1542 (2001)

[19] K. Tanaka, M. Oumi, T. Niwa, S. Ichihara, Y. Mitsuoka, K. Nakajima, T. Ohkubo, H. Hosaka and K. Itao, "High Spatial Resolution and Throughput Potential of an Optical Head with a Triangular Aperture for Near-Field Optical Data Storage," Jpn. J. Appl. Phys., Vol 42, P. 1113 (2003)

[20] X. Shi, L. Hesselink, and R. L. Thornton, "Ultrahigh light transmission through a C-shaped nanoaperture," Opt. Lett. Vol. 28, No.15, P. 1320 (2003)

[21] K. Tanaka and M. Tanaka, ”Optimized computer-aided design of I-shaped subwavelength aperture for high intensity and small spot size,” Opt. Commun. Vol. 233, P. 231 (2004)

[22] T. W. Ebbesen, H. J. Lezec, H. F. Ghaeml, T. Thio and P. A. Wolff, “Extraordinary optical transmission through sub-wavelength hole arrays,” Nature Vol. 391, P. 667 (1998)

[23] T. Thio, K. M. Pellerin, R. A. Linke, H. J. Lezec and T. W. Ebbesen, “Enhanced optical transmission through a single subwavelength aperture,” Opt. Lett. Vol. 26, P. 1972 (2001)

[24] H. J. Lezec, A. Degiron, E. Devaux, R. A. Linke, L. Martin-Moreno, F. J. Garcia-Vidal, T. W. Ebbesen, “Beaming light from a subwavelength aperture,” Science Vol. 297, P. 820 (2003)

[25] F. J. Garcia-Vidal, L. Martin-Moreno, H. J. Lezec and T. W. Ebbesen. “Focusing light with a single subwavelength aperture flanked by surface corrugations,” Appl. Lett. Vol. 83, P. 4500 (2003)

[26] A. Degiron and T. W. Ebbesen, “Analysis of the transmission process through single aperture surrounded by periodic corrugations,” Opt. Express Vol. 12, P. 3694 (2004)

[27] J. J. Sakurai, *Modern Quantum Mechanics*, New York, Addision Wesley Longman (1994)

[28] C. Kittel, *Introduction to Solid State Physics*, New York, John Wiley & Sons (1996)