§27. Numerical Analysis for Design of Tapered Structure of Fiber Probes

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Improvement of the optical throughput of metal-coated fiber probes is the important issue in terms of the applications of near-field scanning optical microscopy (NSOM) to the spectroscopic studies and optical recordings. Recent experimental studies[1,2] show that the transmission efficiency of light through the fiber probe is subject to the taper structures of metal-cladding region. In Ref.1, for the enhancement of the throughput, it is proposed to shorten the narrow metal-cladding region with strong optical losses by making the double-tapered structure. Recently, with the progress of computational work, the numerical analysis has come to be recognized as a powerful tool for deep understanding of the electromagnetic field in the tapered waveguide and the vicinity of an aperture, and for the systematic design of highly efficient probes. The finite-difference time-domain (FDTD) method[3-5] is one of the most promising methods for the above purposes, because it can be easily applied to actual three-dimensional problems. We have reported a FDTD simulation for the double-tapered structure in Ref.6, in which the spatial resolution beyond the conventional NSOM is successfully reproduced by the simulation.

Here we show a FDTD simulation, which corresponds to the experimental configuration in Ref.1. Figure 1 illustrates the FDTD geometry of the probe model. A fiber probe with a double- or single-tapered structure collects luminescence (λ=1μm) from a quantum dot (x-directed dipole radiation) buried λ/40 beneath the semiconductor surface. The radiation caught by the aperture with a diameter of λ/5 propagate in the tapered part clad with perfect conducting metal. The signal intensity is evaluated by calculating the light power finally coupled to the ordinary waveguide (optical fiber) region. The simulation box consists of 120x 120x360 grid in x, y, and z directions. The space step is λ/40. The calculation is done for three types of probes whose dimension are summarized in Table 1. The sample No.1 is a single-tapered probe. The sample No.2 is a single-tapered probe which has a shorter tip length than that of the sample No.1. The sample No.3 is a double-tapered probe whose cone angle of the tip is the same as that of the sample No.2. The calculation shows that the ratio of signal intensity for the sample No.1-3 is 1:32:100. It is clear that a large cone angle contributes to high collection ability since this structure minimizes the length of cutoff region. In addition, the double-tapered probe makes the coupling of light into the normal waveguide more efficient than the single-tapered probe with the same cone angle. The collection efficiency and spatial resolution of the double-tapered probe in Ref.2 is also reproduced by this FDTD simulation.

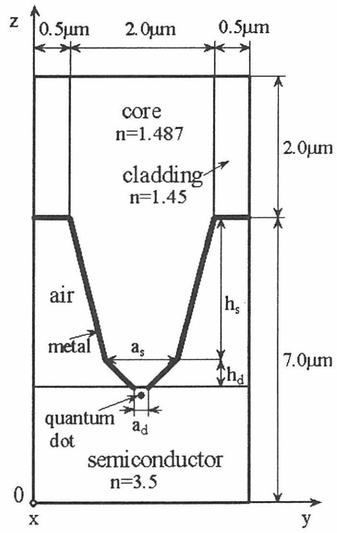

Fig. 1. Cross-section diagram of the simulation model

Sample No.	h_s	a_s	h_d	a_d
1	3.6	0.2		
2	0.9	0.2		
3	2.0	1.0	0.4	0.2

Table I Parameters (in μm) in Fig.1.

References

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