

Chapter 1

Introduction

1.1 Utilization of the Optical Near-Field

Progress in DRAM technology requires improved lithography. It is estimated that technology nodes should reach to 16 nm by the year 2019 [1]. Recent improvements in the immersion lithography using an excimer laser (wavelengths of 193 nm and 157 nm) have resulted in the technology nodes as small as 45 nm. Further decreases in the node size are expected using an extreme ultraviolet (EUV) light source with a wavelength of 13.5 nm. However, the resolution of the linewidth is limited by the diffraction limit of the light. To overcome this limitation, it is necessary to use the optical near-field to exceed the diffraction limit of light. The concept of the optical near-field was proposed [2–4] as a localized electric field at a metallic aperture (Fig. 1.1). Based on scalar theory [5], when the size of the aperture is much smaller than the wavelength, the scattered light has a larger wavenumber than the incident light. Additionally, to hold the law of momentum conservation, the wavenumber normal to the aperture has a negative value. That is, the scattered light normal to the aperture cannot propagate. Thus, it is referred to as an evanescent wave. Over the past decade, utilization of the optical near-field has led to significant progress in various applications, including nanoscale imaging [6, 7], ultra-high density recording [8, 9], and plasmonics [10].

The optical near-field was commercialized due to improvements in fiber probes. Although the generation of the optical near-field was predicted in the 1920s [2], it was not realized until the fiber probe was developed as an optical near-field source. Initial advancements were made in the field of scanning probe microscopy using the pulling/etching technique [11]. Reproducible high-throughput fiber probes were developed using the sophisticated method of chemical etching process, the reproducible high throughput fiber probes were developed [12, 13]. More recently, the author, Yatsui, developed a fiber probe with a throughput of 0.1 for an aperture diameter of 100 nm [14–17] (Fig. 1.2).

In addition to generating optical near-field localization, another unique property was developed. In the nanoscale materials, a photon can be coupled with an electron,

Fig. 1.1 Schematic of the generation of the optical near-field at the nanometer scale aperture

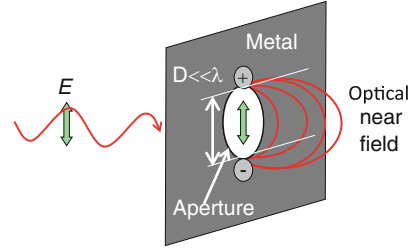


Fig. 1.2 Progress in the fiber probe

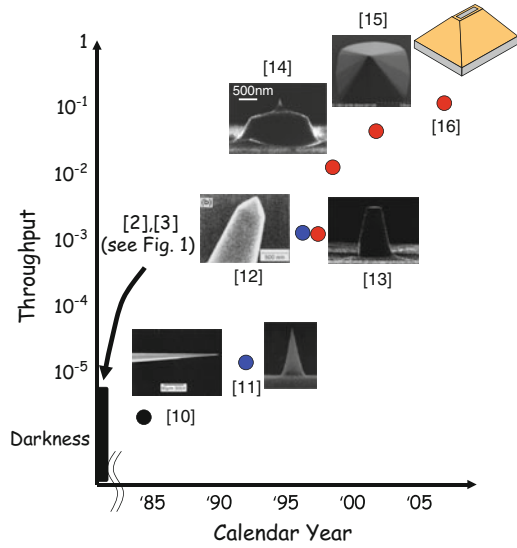
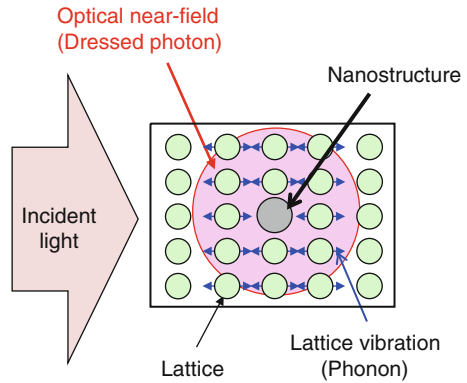
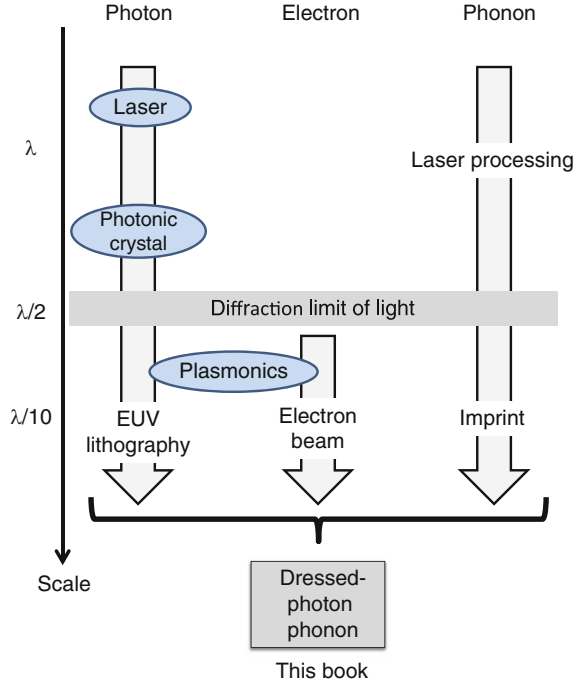


Fig. 1.3 Schematic of dressed photon and phonon



known as a dressed photon. The dressed photon is a virtual photon, and it can also couple with a phonon as a lattice vibration in the surroundings (Fig. 1.3). In their final form, the dressed photon and phonon act as a quasiparticle, in which the energy of the dressed photon and phonon, E_{DP-P} , is larger than that of the

Fig. 1.4 Fabrication trend using various carriers



dressed photon, E_{DP} , and the free photon, E_{FP} ($< E_{DP}$) [18, 19]. This indicates that at the nanoscale, photons can be excited, and this can be achieved using a unique fabrication process.

Various nanoscale fabrication processes have been developed using phonons (laser processing [20] and imprint [21]), electrons (electron beam (EB) lithography [22]), and photons (photolithography [23]). In the nanoscale materials, phonons, electrons, and photons can be coupled with each other and they cannot be treated individually. The coupled state of these three carriers is known as the dressed photon and phonon (see Fig. 1.4). In this book, we treat the photons as being in the mixed state of a phonon, electron, and photon, i.e., a dressed photon and phonon.

Before discussing the dressed photon and phonon, this book begins by addressing the feasibility of nanoscale chemical vapor deposition using optical near-field techniques, which can achieve size and position control on the nanometer scale is reviewed in Sect. 1.2. A probe-less fabrication method for mass-production is also demonstrated (see Sect. 1.3). Based on the near-field fabrication technique, nanophotonic fabrication using the dressed photon and phonon is described in Sect. 1.4.

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