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Microarrays of near-field optical probes with adjustable dimensions

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Abstract

We present the fabrication and the characterization of high-density microarrays comprising thousands of near-field optical probes. Two types of microarrays have been prepared by adapting the SNOM methodology: arrays of uncoated fiber nanotips (i.e. apertureless probes) and arrays of apertures with adjustable subwavelength dimensions. Such arrays were fabricated by retaining the coherent structure of monomode optical fiber bundles and therefore keeping their imaging properties. The size of the apertures in a microarray was tuned at the nanometer scale by modifying the fabrication parameters. Far-field characterization of these near-field probe arrays shows completely different behavior depending both on their architecture and on their characteristic size. The angular distribution of the far-field intensity transmitted through the aperture arrays is used to determine the optical size of such diffracting apertures. Aperture radii ranging from 95 to 250 nm were found in good agreement with SEM data. Furthermore, each nanoaperture of the array is optically independent in the far-field regime. Eventually, this study demonstrates potential applications of these imaging arrays as parallel near-field optical probes in both configurations (apertureless and with apertures).

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Various configurations of scanning near-field microscopy (SNOM) have been developed in the last decades in order to collect optical, spectroscopic and topographic information far beyond the classic Abbé diffraction limit. A key element to

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achieve a subwavelength resolution is the size and geometry of the near-field optical probe which is used as a nanosource and/or a nanodetector, depending on the selected mode. In aperture-based SNOM, the classic probe is a tapered optical fiber coated on the sides with a gold or aluminum film in order to form a subwavelength aperture at the tip apex. Light is confined to the aperture which is scanned in the optical near-field region over the sample surface. The resolution is limited by the finite skin depth of the metal film forming the aperture and by the low light throughput. Another approach is to generate near-field images by an apertureless probe. It has been reported that this microscopy could lead to higher lateral resolution [1–6]. The near-field which is scattered by the nanotip in the vicinity of the surface is thus used as a light nanosource. In the apertureless version of the SNOM, the probe is usually a metal tip [1,7–9] or an uncoated optical fiber tip [6,10–12]. The resolution is then mainly related to the radius of curvature of the tip apex.

In a precedent article, we described the electrochemical and optical properties of aperture array [13]. We demonstrated that the gold rings forming the aperture array could be used as diffusively independent nanoelectrode array [13]. In addition, far-field characterization of the array shows a diffractive behavior [13].

The purpose of this work is to continue our development of useful optical and electrochemical probe arrays [13–16]. In this article, we report the fabrication procedure of near-field optical probe arrays with various structures. Therefore such different arrays lead to diverse optical properties. The far-field optical characterization of ordered arrays of apertureless probes as well as of sized-controlled subwavelength apertures is detailed. The fabrication procedure [13,16] which is mainly adapted from aperture SNOM technology [17–20] has been improved in order to fabricate apertures with adjustable subwavelength dimensions. In brief, a bundle comprising 6000 individually cladded 3–4 μm diameter monomode optical fibers formed the base for the fabrication of our aperture array. The coherent structure of the bundle used in this work allows transmitting an image with a micrometer resolution [21]. Conical nanotips were created at each optical fiber core by using the difference in wet etching rates between the GeO_2-doped core and the fluorine-doped clad [17,19,20]. The schematic representation of the nanotip (i.e. apertureless probe) array is displayed schematically on Fig. 1A. Fig. 3A shows the scanning electron micrograph (SEM) of a single nanotip in the array. The radius of curvature of the tip is less than 50 nm. The diameter of the base of the cone and its height are 2.5 and ~3 μm, respectively (Fig. 3A). In order to fabricate the aperture arrays, we used this nanotip array as a starting material. Indeed, the surface of the nanotips was sputter-coated with a gold film and then insulated

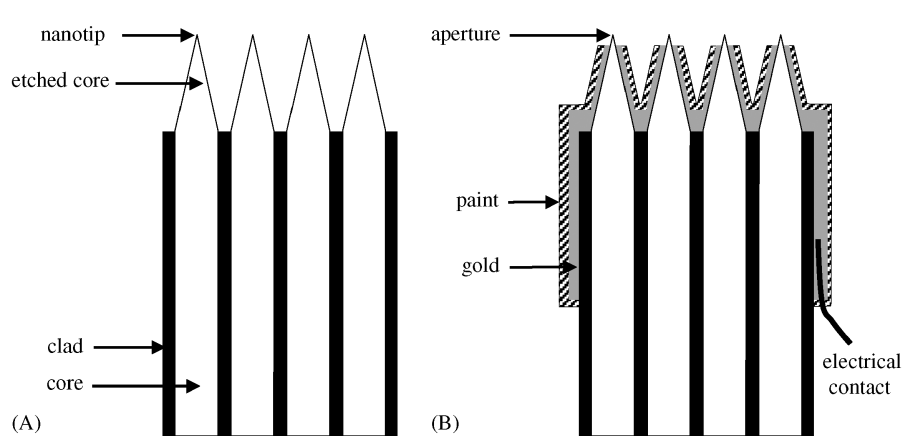

Fig. 1. Cross section schematic representation of (A) the apertureless probe microarray and (B) the nanoaperture microarray.