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تبدیل امواج میراشونده به مدهای انتشاری با استفاده از تکنیک تمام نگاری

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چکیده- برای دستیابی به اطلاعات مربوط به ابعاد زیرطول موج یک جسم و تشخیص آنها، باید اطلاعات موجود در امواج میراشونده‌ای که از جسم پراکنده می شوند را استخراج نمود. واضح است که این امر در ناحیه میدان راه دور جسم امکان پذیر نخواهد بود. در اینجا با استفاده از مفهوم تمام‌نگاری و به صورت تئوری نشان می‌دهیم که می‌توان با ثبت امواج میراشونده بر روی لایه حساس به نور و اعمال تغییر در فرکانس فضایی آنها، این امواج را به امواج انتشاری تبدیل کرده و در نتیجه اطلاعات موجود در آنها را در ناحیه راه دور استخراج نمود.

کلید واژه- تصویربرداری زیرطول‌موج، تداخل، حد تفرق.

Converting Evanescent Waves into Propagating Modes Using Holography

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Abstract- In order to obtain information about subwavelength features of an object, it is necessary to detect evanescent waves scattered from the object, which is not possible in far field region. Here, based on holography concept, we show theoretically that we can record evanescent waves in a photoresist layer and apply a shift in their spatial frequencies. This will result in evanescent to propagating wave conversion and can be used for detecting information about subwavelength features of the object in far field.

Keywords: Subwavelength imaging, interference, diffraction limit.

1. Introduction

When imaging an object with subwavelength features, information about subwavelength parts are encoded into evanescent waves scattered from the object [1-2]. These evanescent waves and their corresponding information will be disappeared in far field region and a resolution limited image of the surface is obtained. This limitation in resolution is known as diffraction limit [3].

Up to now, various methods have been introduced for converting evanescent waves into propagating modes and providing images with subwavelength resolution. The previously developed methods include methods based on metamaterials [4-5], complex nano-structures [6-9], or fluorescent materials [10-13]. However, complexity involved in implementation of these methods has limited their application for subwavelength imaging [14]. Near-field imaging techniques in which evanescent waves are detected by a near-field probe located very close to the object, can also be used to achieve super resolution images [15]. However, these techniques have a limited observation area and are time consuming.

Here, based on holography concept and without using complex materials, we show that an evanescent wave can be recorded in a photoresist layer and its transverse wavenumber can be shifted into propagating range, using an appropriate reconstruction wave. This evanescent to propagating wave conversion technique can be used for recovering information about subwavelength features of an object and therefore can be used for imaging beyond the diffraction limit.

The paper is organized as follows. Section II includes discussion of theory of converting evanescent waves into propagating modes using the holography concept. In section III, we use this conversion for subwavelength imaging. Finally, in section IV we conclude the paper.

2. Theory

In holography, first, field scattered by an object is interfered with a reference wave and the resulted intensity pattern is recorded. Then by using a reconstruction wave the object field is regenerated [1]. Although holography is a powerful imaging technique especially for phase objects and has different applications, its resolution is limited to diffraction limit [1], [16-17].

In this section, we show that using recording and reconstruction processes, an evanescent wave can be recovered and converted to a propagating wave. Consider the wavefront due to a sample, $a(x,z)$, is incident on a photoresist layer, located in the close distance d above the sample (see Fig. 1(a)), and interferes with a mutually coherent reference wave, $A\exp(jk_r x)$. Therefore the recorded intensity pattern on the photoresist, will be equal to:

$$I(x)=|A|^2+|a(x)|^2+A^*a(x)e^{-jk_r x}+ Aa^*(x)e^{jk_r x}. \quad (1)$$

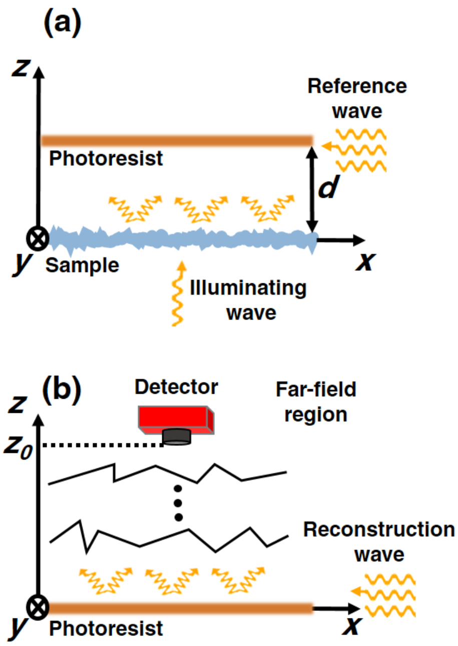

Fig. 1: (a) Recording an evanescent wave. (b) Recovering recorded information.

Due to Eq. (1), the transmittance of the photoresist can be written as [1]:

$$t_a = t_b + \beta(|a(x)|^2 + A^* a(x) e^{-jk_r x} + Aa^*(x) e^{jk_r x}), \quad (2)$$

where t_b and β are constant parameters and asterisk denotes complex conjugate quantities [1]. In the proposed method, the reference wave is incident with much larger amplitude with respect to the amplitude of the object wave. Therefore, the second term on the right hand side of Eq. (2) can be neglected [1]. Now reconstruction wave, $B\exp(jk_r x)$, is applied to the fixed photoresist, as shown in Fig. 1(b). Therefore the transmitted field of:

$$U_t = t_b B e^{jk_r x} + \beta B A^* a(x) + \beta B A a^* e^{j2k_r x}, \quad (3)$$

will be produced and can be detected in far field region by a detector (see Fig. 1(b)). In far field region, the first and second terms on the right hand side of Eq. (3), are in fact the reconstruction wave, and propagating section of the angular spectrum of the sample field, respectively and are known. According to the last term of Eq. (3), which is the only unknown term of equation, the angular spectrum of the sample field is shifted by the value of $2k_r$, and a range of evanescent waves can be transferred into propagating range. Therefore, using Eq. (3), the information correspond to a range of incident evanescent waves can be recovered in far field region.

3. Subwavelength Imaging

In this section we use the proposed technique to resolve two sources separated by a gap with width of $s=\lambda/7$, which is much beyond the diffraction limit. The simulated structure is shown in Fig. 2.

First, the propagating section of the angular spectrum of the sample field is computed. In this regard, the electric field is recorded at a distance of 2λ from the sample (far field region), as shown in Fig. 2(a), and its Fourier transform is computed. Then the interference intensity pattern caused by the field of the sample and a reference wave with transverse wavenumber of k_0, is recorded at near field region of the sample, as shown in Fig. 2(b). Now we multiply the recorded intensity by *exp(jk_0x)*, which acts like a reconstruction wave. By taking these steps, we can recover information contained in transverse wavenumbers in the range of $[k_0, 3k_0]$. Moreover, By reversing the direction of reference and reconstruction waves, information contained in transverse wavenumbers in the range of $[-3k_0, -k_0]$, can also be extracted.

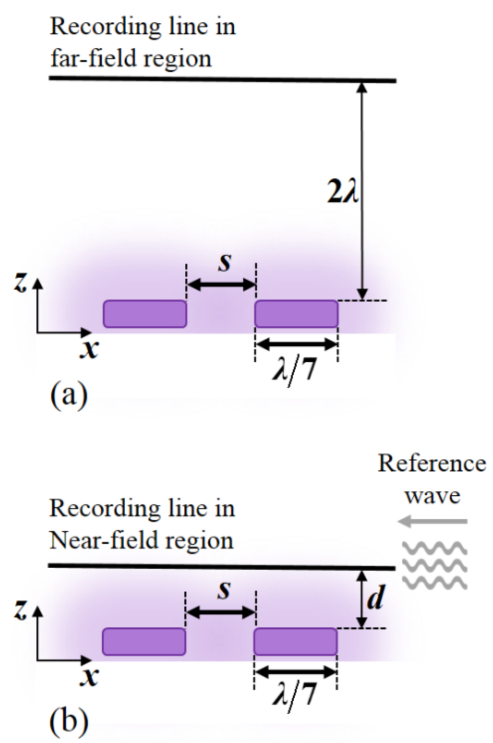

Fig. 2: (a) Recording the information contained in propagating section of the angular spectrum, (b) recording the interference intensity pattern in the near field region.

The resulted image of the sources, using the explained method, is shown in Fig. 3, and compared with the image of the sources when the proposed technique is not used. The intensity distribution in near field region of the sources (object plane), is also shown in Fig. 3 with black solid line. As shown in this figure, two sources are distinguishable according to Rayleigh criterion [3], when using the proposed technique for imaging (see the blue dashed graph in Fig. 3). However, without using the proposed technique, only the propagating section of the angular spectrum, will contribute in the image (see the red circle graph in Fig. 3) resulting in an incomplete image in which two sources have been combined with each other and are not distinguishable.

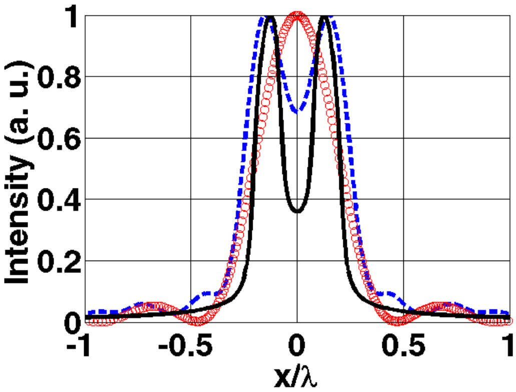

Fig. 3: The reconstructed image using proposed technique (dashed line), object (solid line), and reconstructed image without the proposed technique (circle line).

4. Conclusion

In this paper we proposed a new method to convert evanescent waves into propagating modes and in order to recover the information contained in evanescent waves for subwavelength imaging. The capability of the proposed method was verified by resolving two sources separated by a $\lambda/7$ gap. It should be noted that by using larger transverse wavenumbers for reference and reconstruction waves, a higher resolution can be achieved.

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