Comment on "Submicron imaging with a planar silver lens" [Appl. Phys. Lett. 84, 4403 (2004)]

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Melville, Blaikie, and Wolf[1] reported a submicron imaging using a 120-nm-thick silver slab. Diffraction-limited features as small as 350 nm (at a 700 nm period) were imaged onto the photosensitive material with the silver slab. The image resolution is said to be improved compared to a control experiment with 120 nm of poly(methylmethacrylate) (PMMA) between the mask and the photoresist (without silver film). Despite an extensive and intended connection to the superlens theory[2] throughout the letter and the following news thereof,[3] this experiment in our opinion is irrelevant to the referred superlens theory. This comment clarifies the interpretation of the experiment reported by Melville *et al.* Regarding the work reported in Ref. 1, we believe that the 120 nm silver film does not help to record an image of the mask. As we will show, the transmission behavior through this thick silver film shows that incident waves are strongly attenuated for all near field features including propagating and evanescent waves, thus the system does not enhance any evanescent waves as a superlens does. The blurred image recorded by the control experiment is in our opinion likely due to an excessive exposure.

The basic theoretical idea suggested by Pendry[2] is based on the potential of a silver film to transmit and strongly enhance evanescent waves which carry subwavelength information (originally scattered by the mask). This so-called superlensing effect may be used to rebuild a subwavelength image.[4] But because the minimum feature size of the mask in this experiment is about the incident wavelength, the imaging reconstruction of the mask does not require a subwavelength imaging method, in other words, is not relevant to a superlens that significantly enhances evanescent waves scattered by the object.

In Fig. 1, we calculate the transmission transfer function of TM waves (like in the experiment Fig. 1 of Ref. 1) for a 120 nm silver at 365 nm wavelength, which is the amplitude ratio of the transmitted H field over the incident H field as a function of the transverse wave number. It can be seen that the 120 nm silver film actually acts like an attenuator. For instance, for the 700 nm period object, the corresponding incident propagating waves have only less than 1% of the transmitted intensity. More importantly, this 120 nm silver film does not enhance evanescent waves. Since a broadband wavelength of 300–450 nm is used in Ref. 1 as described in detail in Ref. 5, we further found that the transmission for 300–450 nm has very similar behavior as 365 nm. A superlens effect is expected only for wavelength longer than 400 nm for the system used in Ref. 1 for a very narrow band of transverse wave number corresponding to evanescent waves that cannot be generated by the mask in the experiment of Ref. 1.

A blurred optical image shown Fig. 2(a) of Ref. 1 is obtained by a control experiment using the same thickness of PMMA (120 nm) but without silver film. In contrast, the image obtained using a silver film sandwiched between two 60 nm layers of PMMA is in agreement with the mask topography. According to Melville *et al.*,[1] the image is blurred because of diffraction effect in the PMMA. In our opinion, the blurred image is likely due to an overexposure. We note that a comparable exposure time of 2 min is used in both the experiment with silver and the control experiment. In the control experiment, the transmission will be significantly higher than the experiment with silver where less than 1% of the energy is transmitted through this silver film. We think that the appropriate exposure time used in the control experiment should be drastically reduced to obtain a good image. Therefore, the blurred image in the control experiment cannot serve as a trustworthy verification or confirmation in Ref. 1.

Despite the very low transmission factor of waves through this thick (120 nm) silver, the recorded image shown in Fig. 2(b) of Ref. 1 is in agreement with the mask topog-

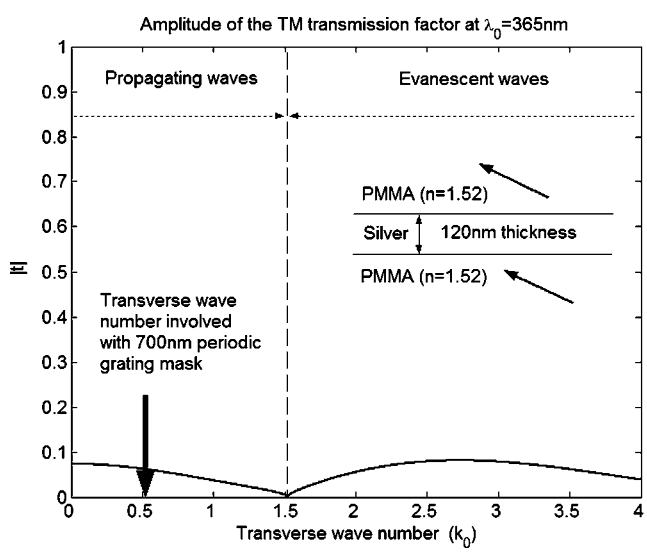

FIG. 1. Computed amplitude transfer function of 120 nm slab silver. It is clear that both propagating and evanescent waves are attenuated by silver slab, leaving no advantage of resolving subwavelength features.

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raphy showing that a silver slab can transfer a feature of diffraction-limited size. An interesting aspect is that actually the silver film does not worsen the diffraction of light scattered by the mask. It may be attributed in part to the fact that waves inside a metal like silver are mostly evanescent because the real part of the permittivity is negative and the imaginary part of the permittivity is small at the wavelength of the incident radiation. As a consequence only a very small phase delay is introduced along the transmission across the metal leading to very small additional diffraction effect. Because of identical total thickness of PMMA in both experiments and because the silver film could only provide additional diffraction effect if there is any, this cannot support the authors' claim of diffraction effect resulted in the blurred image in the control experiment. A 120 nm thick silver film in this work merely served as an attenuator and should not help the imaging even at diffraction-limited size.

To summarize, it is misleading to make a connection to or use the superlensing theory to justify the imaging ability of this 120 nm thick silver film in Ref. 1, since the main function of the film in this work is attenuating incident propagating waves by absorption through the film. The control experiment did not provide any conclusive confirmation that a 120 nm thick silver film helps to enhance the resolution of the described imaging due to possible overexposure.

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