van Hulst *et al.* Reply: In Ref. [1] we have presented the first visualization of the phase evolution of the optical field of propagating guided modes, using heterodyne interference photon scanning tunneling microscopy (PSTM). The Comment of Vohnsen and Bozhevolnyi [2] focuses mainly on our observation of phase singularities that are expected at positions of destructive mode beating. In particular, they stress the fact that the singularities originating from TE_{00}-TM_{00} mode interference cannot occur, as the local intensity is not zero. Actually this notion is not particularly new.

Already in the original Letter [1] we pointed out that ordinarily TE and TM modes do not interfere due to their perpendicular polarization. It is the polarization conversion, inherent to near field optics and subwavelength probes, that leads to a quasi-interference of the mutually perpendicular fields. We analyzed the subwavelength polarization coupling and resulting interference in a previous experimental study [3]. As a result the singularities occur at points where the amplitudes of the local TE and TM fields, as projected on the detection system, are equal (nonzero) and have opposite signs. The position of TE-TM singularities is a measure for the relative amplitude of the TE and TM modes [4]. Evidently the singularities shift in a transverse direction depending on the ratio between TE and TM excitation and the amount of polarization coupling.

In practice a multitude of singularities is observed due to interference between all excited modes in the waveguide. Here we present, for completeness, singularities due to TE_{00}-TE_{01} interference, i.e., points where the modal TE field amplitudes are equal and the fields are out of phase leading to destructive interference. Figure 1 displays singularities both with topological charge $+1$ and -1. In the propagation direction (vertical) the singularities influence the phase pattern over many wavelengths due to the long TE_{00}-TE_{01} mode beat length [1]. In the transverse direction (horizontal) the singularity is very sharp due to the large gradient of the TE_{00}/TE_{01} field ratio in that direction. The edge sharpness of the transverse π phase jump is better than 50 nm. These highly localized phase features clearly corroborate the subwavelength phase resolution, as recently also reported by Nesci *et al.* [5]. Here, we point out that this phase resolution claim is based on a localized discrete step in the phase, in contrast to the objections by Vohnsen and Bozhevolnyi [2] based on periodic optical intensity features.

For clarity it should be noted that, as PSTM probes the evanescent field above the waveguide, not the internal waveguide field, the singularities occur at positions where the local evanescent field amplitudes match. All singularities (TE-TE and TE-TM) will shift in a transverse direction depending on the distance to the waveguide due to the modal dependence of the evanescent decay away from the waveguide surface.

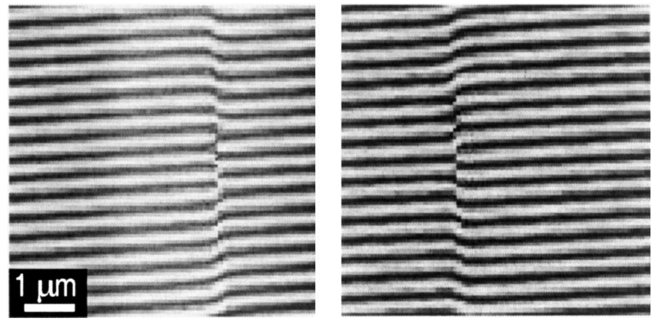

FIG. 1. Measured phase evolution of the optical field at two positions along a Si_3N_4 channel waveguide (as in [1]), obtained by phase sensitive PSTM. Both TE_{00} and TE_{01} are excited. The cosine of the phase is shown. Singularities both with topological charge $+1$ and -1 are observed. At the singularity the phase makes a π jump within 50 nm in the transverse direction (horizontal). The two images ($6.3 \times 6.3\ \mu m^2$) are obtained at different positions along the waveguide separated by the TE_{00}-TE_{01} mode beat length.

Finally, we remark that in application of local phase mapping to photonic structures, such as small photonic crystals, many phase singularities are observed, which give direct insight in the local field amplitude, the amount of depolarization, and the spatial frequency spectrum [6].

Henkjan Gersen is gratefully acknowledged for imaging and preparation of Fig. 1.

Niek van Hulst, Marcello Balistreri,
Jeroen Korterik, and Laurens Kuipers
Applied Optics Group
MESA+ Res. Inst.
Department of Applied Physics
University of Twente
P.O. Box 217
7500AE, Enschede, The Netherlands

Received 28 June 2001; published 28 November 2001
DOI: 10.1103/PhysRevLett.87.259402
PACS numbers: 42.25.Bs, 07.60.Ly, 07.79.Fc, 42.25.Hz

[1] M. L. M. Balistreri, J. P. Korterik, L. Kuipers, and N. F. van Hulst, Phys. Rev. Lett. **85**, 294 (2000).
[2] B. Vohnsen and S. I. Bozhevolnyi, preceding Comment, Phys. Rev. Lett. **87**, 259401 (2001).
[3] M. L. M. Balistreri, A. Driessen, J. P. Korterik, L. Kuipers, and N. F. van Hulst, Opt. Lett. **25**, 637 (2000).
[4] M. L. M. Balistreri, J. P. Korterik, L. Kuipers, and N. F. van Hulst, J. Lightwave Technol. **19**, 1169–1176 (2001).
[5] A. Nesci, R. Dändliker, and H. P. Herzig, Opt. Lett. **26**, 208 (2001).
[6] E. Flück, A. M. Otter, J. P. Korterik, M. L. M. Balistreri, L. Kuipers, and N. F. van Hulst, J. Microsc. **202**, 104 (2001).

