A New Role for Surface Plasmons

C.H. Gan, G. Gbur and T.D. Visser

Ever since the discovery that sub-wavelength-sized apertures can transmit much more light than expected,[1] many researchers have been investigating the role of surface plasmons in nano-optics. These surface modes that propagate along the interface of a metal and a dielectric have a number of intriguing properties. Excited by light that is incident on the interface, they can travel relatively long distances (dozens of microns), reflect off surface imperfections, interfere with other surface plasmons and be converted back into a propagating light field.

The question of whether plasmons are helpful in boosting the transmission of nano-apertures has long occupied scientists. The recent results of a simple experiment show clearly that plasmons can actually both help and hinder the transmission process.[2] By carrying out Young's double-slit experiment with a thin gold film and varying the wavelength of the incident field, one can observe a strong periodic modulation of the total transmission. This can be understood by considering the interference of plasmons that are generated at one slit and converted back into radiation at the other, with the light that is transmitted directly.

This modulation only occurs for TM illumination, the only polarization for which plasmons can occur. Indeed, even when only a single slit is illuminated, a two-slit interference pattern can sometimes be observed.[3] Again, the explanation is that plasmons that are excited at the illuminated slit travel to the other, "dark" slit, where they reappear as a propagating light field.

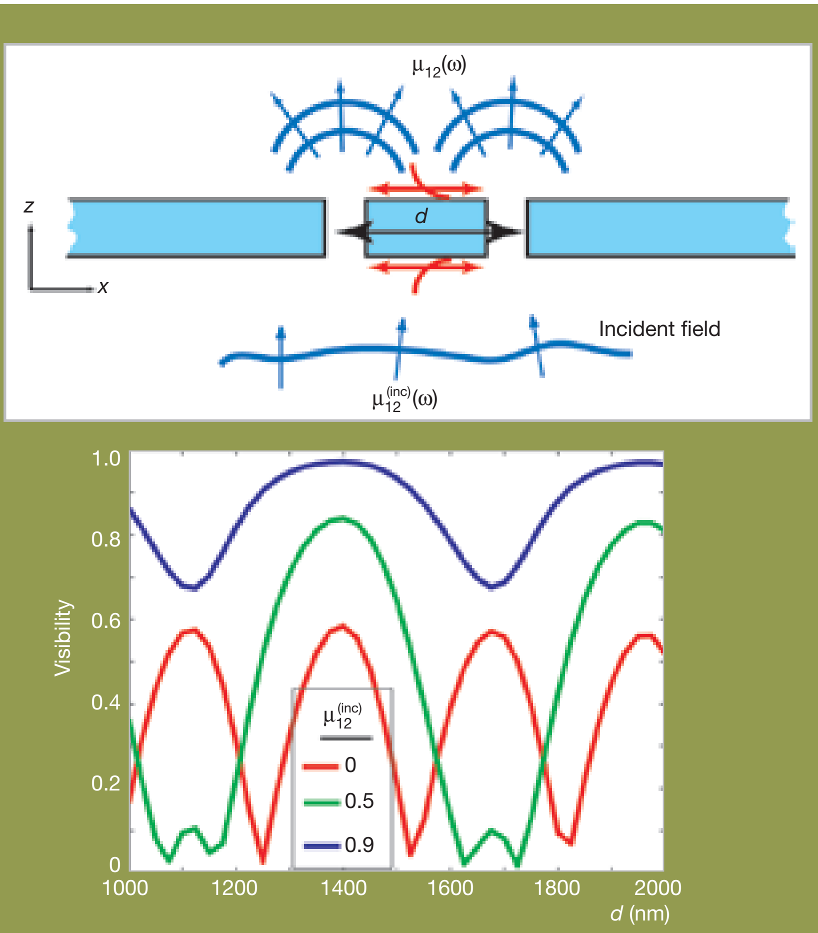
The question of whether plasmons can change properties of optical fields besides transmission efficiencies was recently addressed. It is well known that the state of coherence of a wave field can induce changes in its spectrum and its state of polarization on propagation, even through free space.[4] In Young's double-slit experiment, a change in coherence translates into a change in the quality (or "visibility") of the interference fringes. This can be achieved by illuminating the slits with a linearly polarized beam, and then gradually "switching on" the plasmons by changing the orientation of the polarization.

Strong modulations of the state of coherence of the field that emerges from the slits are predicted when the wavelength of the incident field is varied. The transmitted field can either be more coherent or less coherent than the incident field, depending on the distance between the slits.[5] These predictions are currently being tested experimentally. It looks like this "plasmon-modulated coherence" may add yet another facet to the ever growing role of plasmons in nano-optics. ◭

[C.H. Gan (chgan@uncc.edu) and G. Gbur are with the University of North Carolina at Charlotte. T.D. Visser is with the Free University, Amsterdam, The Netherlands.]

References

1. T.W. Ebbesen et al. Nature (London) **391**, 667 (1998).
2. H.F. Schouten et al. Phys. Rev. Lett. **94**, 053901 (2005).
3. N. Kuzmin et al. Opt. Lett. **32**, 445 (2007).
4. E. Wolf, *Introduction to the Theory of Coherence and Polarization of Light*, Cambridge University Press, Cambridge (2007).
5. C.H. Gan et al. Phys. Rev. Lett. **98**, 043908 (2007).



(Top) Illustration of the geometry for plasmon-modulated coherence in Young's interference experiment. The degree of coherence of the incident field at the two pinholes is $\mu_{12}^{(inc)}(\omega)$, while the degree of coherence of the transmitted field at the two pinholes is $\mu_{12}(\omega)$. (Bottom) Visibility of the interference fringes, as a function of slit spacing *d* and degree of coherence of the incident field.

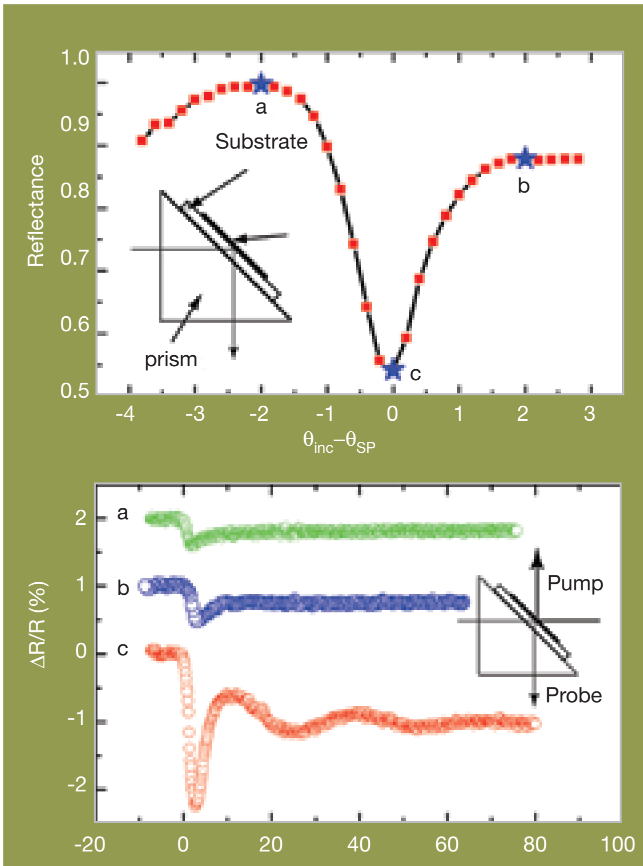
Super-Sensitive Surface Plasmon Probe in Ultrafast Measurements

Jincheng Wang and Chunlei Guo

Time-resolved femstosecond pump-probe measurements are a powerful method for studying electron and lattice dynamics in solid materials. Taking the study of lattice dynamics as an example, the generation of acoustic phonons in solids will induce a change in optical reflectance or transmittance, which should be detectable by a delayed probe pulse.

However, the change of reflectance or transmittance due to acoustic phonons is usually extremely small and often requires a phase-sensitive detection instrument combined with a high repetition-rate laser system (e.g., a fs oscillator running at tens of MHz) to yield a high signal-to-noise ratio. Direct monitoring of light reflectance or transmittance is usually not suitable for detecting acoustic phonons when a low-repetition-rate laser system is used (e.g., a 1-kHz fs amplifier), since the signal-to-noise ratio decreases for phase-sensitive detection when the laser repetition rate decreases.[1]

Recently, applications of surface plasmons have attracted much attention. A surface plasmon (SP) is an electromagnetic wave coupled with collective electron-density oscillation on a metal-dielectric interface, decaying evanescently on both sides of the interface.[2] In this work, we use surface plasmons as a sensitive probe technique to detect acoustic phonons in a silver (Ag) film following impulsive optical excitation with a low-repetition-rate (1 kHz) fs laser system.[3]



(Top) The dependence of light reflectance on the incident angle (θ_{inc}) in the vicinity of the SP-resonance angle (θ_{sp}). The inset shows the probe geometry. (Bottom) Normalized pump-probe signal for the probe beam incident at –2°, 2° and 0° off the SP-resonance angle, marked by *a*, *b* and *c* in the top portion of the figure, respectively. The inset shows the pump-probe experimental setup.

Experimentally, a 55-nm Ag film was excited by fs pump pulses and its change in properties is detected by a probe pulse incident in the vicinity of the SP-resonance angle, which is determined by measuring the dependence of reflectance on the angle of incidence. The figure shows the time-resolved pump-probe reflection change ($\Delta R/R$) at both SP-resonance and non-SP-resonance angles. As shown by curves *a* and *b* in the bottom portion of the figure, for the probe beam incident at an angle of about 2° off the SP-resonance angle, the initial change of $\Delta R/R$ decays monotonously to a near-constant value.

However, for the probe beam incident just at the SP-resonance angle, a periodic oscillation is clearly seen in the $\Delta R/R$ signal. These oscillations are due to a pump-induced coherent acoustic phonon pulse traveling back and forth between the two surfaces of the Ag film.

Our study shows that the enhanced sensitivity of the SP probe can be understood by considering the change of reflectance *R* with respect to both the real (ε_r) and imaginary (ε_i) parts of a metal's dielectric constant. A certain pump excitation will induce a fixed amount of $\Delta\varepsilon_r$ and $\Delta\varepsilon_i$, and the probe signal change will then be determined by $dR/d\varepsilon_r$ and $dR/d\varepsilon_i$.

Our calculations show that the values of $dR/d\varepsilon_r$ and $dR/d\varepsilon_i$ for the probe beam at SP resonance are significantly higher than those at off SP-resonance, and this explains the enhanced sensitivity of probing at SP resonance.

This study shows that the SP technique is a promising tool for detecting small optical or mechanical property changes in metals on a microscopic scale and is suitable for a variety of applications, such as sensors and MEMS. ▲

[Jincheng Wang and Chunlei Guo (guo@optics.rochester.edu) are with the Institute of Optics at the University of Rochester, N.Y.]

References

1. C. Guo and A.J. Taylor. Phys. Rev. B **64**, 245106 (2001).
2. H. Raether. Springer Tracts in Modern Physics, **111**; 1-133 (1988).
3. J. Wang and C. Guo. Opt. Lett. **32**, 719-21 (2007).