Digital plasmonics: from concept to microscopy

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This concluding chapter summarizes all of the results presented in this thesis. We will remind the reader of the principle of our new method to optically control plasmonic fields in metallic nanostructures, as well as its consequences. We will also remind applications of this broad technique to a more specific contest like plasmonic microscopy.
We started this thesis by introducing Surface Plasmon Polaritons (SPP) as surface waves propagating on metal-dielectric interfaces and by describing the main characteristics of these waves. The goal of this thesis was to introduce a new prospective on controlling at will surface plasmons by tuning the incident optical wavefront via a spatial light modulator (SLM).

The concept of this work for successful control of the SPP waves consisted of four main ingredients: (1) Using the pixels of SLM as secondary plasmonic sources, (2) Actively controlling the amplitude and phase of these secondary plasmonic sources, (3) Smart amplitude distribution of the SPP sources to create a plasmonic arena in which optical effects are separated from the plasmonic ones, and (4) Use of the phase of the plasmon sources to, far from the sources, tune the interference pattern of the propagating SPPs. These four points have been satisfied in all the experiments presented in this thesis. In chapter 2 we started introducing the new concept of plasmonic control in broad context, while in chapter 3 and chapter 4 we applied the concept to experiments specifically oriented toward SPP-sample interaction and plasmonic microscopy, respectively.

In chapter 2 we introduced this new concept in a relatively large context. The main goal of the experiments in this chapter was to tune the interference pattern of the propagating SPP waves on a nanostructured sample to create a plasmonic focus. The sample used was a nanohole array on a gold film. The hole array was used both for coupling the incident light into SPP sources and for detecting the propagating plasmons via their scattering from the grating. Thus the sample had no particular advantage except for providing the in/out coupling of the plasmons. By tuning the phases of the SLM pixels, we tuned the relative phases of the plasmonic sources. The required phase front to maximize the plasmon intensity in one target spot was determined via a feedback loop. This phase front held important information about the SPP propagation. By focusing at a target, the plasmonic Green’s Functions between that target point and the plasmon sources was determined. Such Green’s Functions could not be calculated analytically. This focusing (at any given point) and Green’s Function retrieval via feedback is a general result valid for any kind of sample. Because the large range of samples where the concept can be applied the results presented in chapter 2 are important in a large context.

In chapter 3 feedback loops are not used anymore. The plasmonic interference pattern is tuned using only predictable phase patterns. Instead of focusing at will, in this chapter the fringes from counter propagating SPP waves are controlled. Thus, in this chapter, SPP focusing is given up for
simpler and faster control of plasmonic fringes. The main results were the observation of plasmonic Bloch modes due to the mixture of free space (bare gold film) SPP waves with modes of the sample. The samples were nanohole arrays with different hole periodicity. Because of the periodic corrugations of the sample, SPPs were dressed with the Bloch modes of the structure. The momentum of these waves, measured from the standing intensity pattern of two counter propagating Bloch SPPs, perfectly matched our predictions without any fitting parameter. By tuning the phase front it was possible to shift and/or rotate these fringes with relevant consequences for Structured Illumination Microscopy. A new principle was introduced (but not proven): using high momentum Bloch SPP fringes for high resolution structured illumination microscopy.

In chapter 4 the best featured of the previous experiments are used to demonstrate the principle of a novel plasmon microscope. In this chapter we achieve again plasmonic focusing and scanning (as in chapter 2), but using predictable phase patterns (no feedback used as in chapter 3). To combine the best of the two previous experiments we used a specially designed nanostructure consisting of bare gold regions (arenas) surrounded by nanohole arrays. The hole grating provides the light-to-SPP coupling, while the SPP propagation on a bare gold arena is theoretically predictable (free space). SPPs propagating on bare gold are optically invisible because they do not couple out into light. A few nano scatterers were placed in the arena. Using calculated phase values we scanned the SPP focus on the arena to image the scatterers. Because the SPP wavelength is shorter than the optical one, the SPP focus is sharper than the optical focus and the imaging resolution of this plasmon microscope is better than the diffraction limit.

To conclude, in the first part we described in a broad sense (any metallic nanostructure) the principle of optical control of plasmonic channels by focusing and scanning SPPs via feedback loops. Later, in chapter 3, we naturally built a bridge between the fundamental results of the first part and the fully application oriented results of the last experiment. A new microscope based on SPP waves was demonstrated.