Possibilities in Processing Optical Information in Plasma

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Introduction

Certain holographic techniques might be carried out also in plasma, where the information is captured in the form of a slowly moving wave, such as a cold plasma wave. For example, through stimulated Raman backscattering with a short reference beam, information carried by a laser pulse can be captured in the slowly propagating plasma wave [1]. The plasma wave might persist for a time long compared with the pulse duration. If the plasma is then probed with a second short laser pulse, the information stored in the plasma wave can be retrieved in a second scattered electromagnetic wave. We find that for suitable plasma parameters, non-ideal effects such as collisions, dispersion, and nonlinearities are negligible, so that the recording and retrieving processes can conserve robustly the pulse shape. The process might then be useful for recording and retrieving with fidelity of information stored in optical signals. In addition to simply retrieving it at a later time, the optical information captured in the slow moving plasma wave might be otherwise processed by being probed with more complicated reference beams. Thus, certain operations might be performed on the slower time scale, such as taking the derivative of the pulse form or performing other simple mathematical operations.

The possibility of trapping, storing and retrieving the light pulses has, of course, been realized through alternative means, including the slowing down of light in media such as in an atomic vapor of rubidium atoms. The ultraslow group velocity of electromagnetic waves compresses the laser pulse as it enters the vapor region and increases the pulse propagation time through the medium. Light storage can be enabled by electro-magnetically induced transparency (EIT) effects, wherein an external optical field switches the medium from opaque to transparent near an atomic resonance, letting the laser pulse into the medium. After the whole pulse has entered the system, the control field is turned off, converting the electromagnetic wave energy into the energy of spin excitations in atom vapor, which "stops" the pulse. The stopped laser pulse stored in atomic excitations can be accelerated up to the speed of light again by turning the control field on. The use of plasma, in the manner outlined here, might have the advantage that signals can be processed at relatively high power.

Recording and Retrieving Information

Consider the recording of information, depicted in Fig. 1. An input, or data, pulse A_{in} moves to the z-direction with the information imbedded in the shape of the pulse envelope. A counter-propagating reference pulse or recording pulse, B_{rec} which is of a known shape, propagates to the left. When the two pulses meet in the plasma that separates them, they generate a plasma wave F (z). If the carrier frequency of the recording pulse is downshifted by the plasma frequency from the data pulse, then the resonant Raman 3-wave interaction equations are of the form,

$$A_t + cA_z = -F\,B \tag{1}$$

$$B_t + cB_z = AF^* \tag{2}$$

$$F_t = AB^* \tag{3}$$

where *A (z, t), B(z,t)* and *B(z,t)* are respectively the normalized vector-potential envelopes of the light waves and the plasma wave, with *z* a normalized distance coordinate.

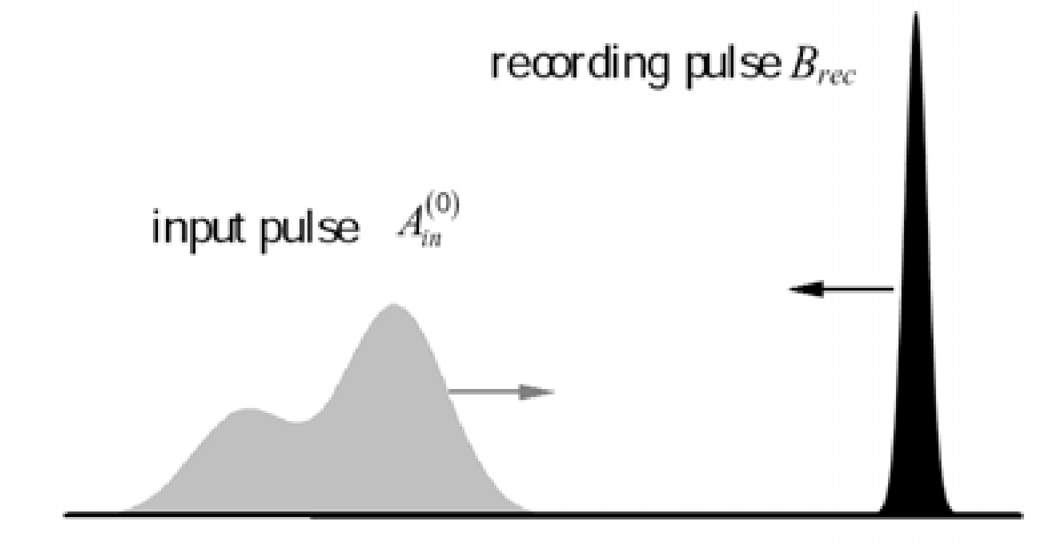

Fig. 1a. Recording an input pulse: initial conditions for data pulse A, recording pulse B. Plasma wave is assumed absent initially.

Suppose that initially there are no disturbances in the plasma, so that *F=0*. Now if the amplitudes are small enough, so that the light pulses can be assumed to be unaffected by their mutual interaction, then evidently after the pulses have crossed, *F(z, t),* as *t* goes to infinity, is the convolution of the unperturbed counter-propagating light pulses. If the reference pulse

B can be made short compare to the characteristic length of a data bit, namely the characteristic variation of *A*, then the pulse envelope *F* takes a shape that is just the twice compressed form of *A(z, t=0), i.e., F(z,t=* ∞ *)* $\propto$ *A(2z, t=0)*. The recording is depicted in Fig. 1b.

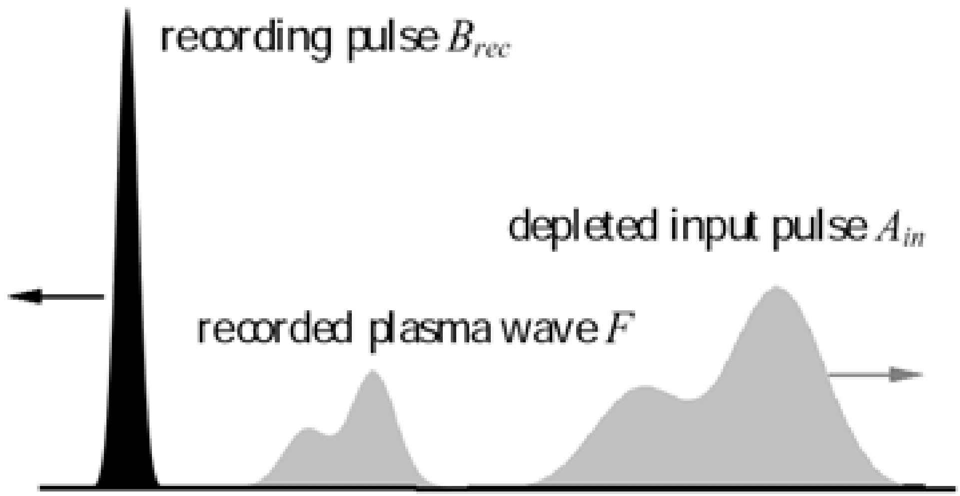

Fig. 1b. Recording the input pulse: final conditions for data pulse A, recording pulse B, and plasma wave.

In reconstructing the envelope *A*, say after several plasma periods have elapsed, a second reference pulse *B* is introduced, where this retrieval pulse is again made short compared to the variation of the plasma wave, which has taken on the characteristic length (twice compressed) or the original data pulse.

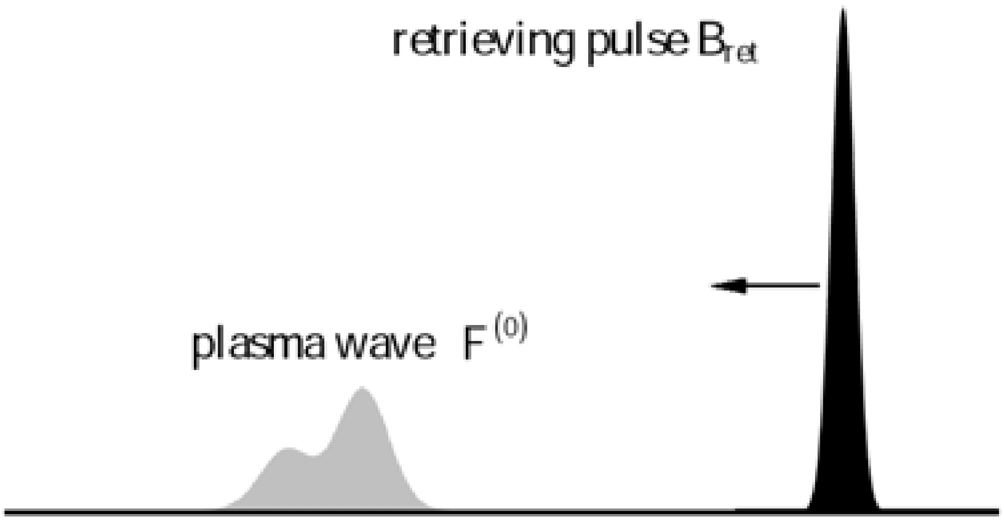

Fig. 2a. Retrieving an input pulse: initial conditions for plasma pulse F and retrieving pulse B. Data pulse is assumed absent initially.

Using now Eq. (1), where the reference retrieval pulse and the plasma wave can be assumed constant, it is clear that a time-delayed data pulse results from the inverse convolution operation or the retrieval pulse with the captured plasma wave, as depicted in Fig. 2b.

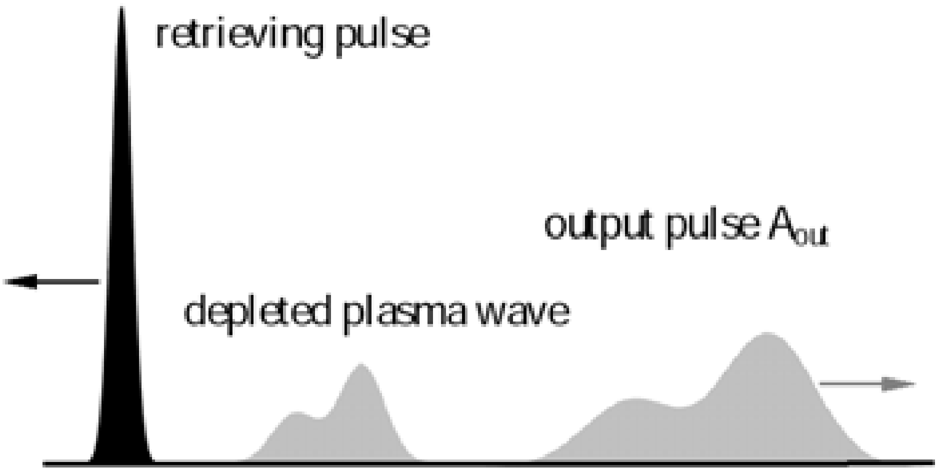

Fig. 2b. Retrieving an input pulse: final conditions for plasma pulse *F*, and retrieving pulse *B*, and output pulse A, which is the reconstituted data pulse.

Discussion

In order for the recording and retrieving to be accomplished with fidelity, the plasma must be sufficiently homogeneous, the resonances must be sufficiently precise, and Landau and collisional damping of the plasma wave must be negligible on the time scales of interest. The likely useful plasma and wave parameters meeting these criteria are outlined in Ref. 1.

Assuming that conditions for recording and retrieval are met, one can envision not only retrieval of the data pulse but also the processing of it. For example, a suitably shaped retrieval pulse, through convolution with the captured wave, can result in differentiation (among other operations) of the original wave. Suppose further that either the recording or retrieval pulses have transverse phase variation, such as focussing or defocusing wave fronts. The transverse phase advances can then be captured either in the plasma wave or in the retrieval process. The result is that the original data pulse upon retrieval can be brought to focus or magnified.

[1] I. Y. Dodin and N. J. Fisch, *Storing, Retrieving, and Processing Optical Information by Raman Backscattering in Plasma*, Physical Review Letters **88**, 165001 (2002).

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