**Modelling and Simulation of Lorentz-Drude Dispersive Material as Nano waveguides by using FDTD Method**

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| **Abstract**  In this work, we theoretically investigate the electric (TE) and magnetic (TM) field behaviours in linear nanowaveguides with different Lorentz-Drude dispersive materials using the finite difference time domain method (FDTD). We simulate the propagation of light in different materials to obtain the maximum efficient media. We investigate the amplitude, extinction and dissipation characteristics of the fields in the nanowaveguides and make comparisons to select the appropriate material for our needs. For electric field we obtain Titanium media for maximum amplitude, Silver media for minimum amplitude, Gold media for maximum extinction, and Titanium media for minimum extinction and Gold media for maximum dissipation, Silver media for minimum dissipation. For magnetic field we obtain Gold media for maximum amplitude, Silver media for minimum amplitude, Gold media for maximum extinction, and Chromium media for minimum extinction and Silver media for maximum dissipation, Chromium media for minimum dissipation. |
| Keywords: Lorentz-Drude Materials, Nano waveguide, FDTD Method |

1. **Introduction**

In dispersive medium permittivity or permeability of medium depends on the wave frequency [1]. At optical frequencies, metals defined as dispersive [2]. At optical and near-infrared frequencies, the permittivity of metals can be describe by Lorentz-Drude (LD) model [3]. The refractive indexes of Lorentz-Drude dispersive materials continuously change under plasma frequency [4]. LD model studies free electrons (intra-band effects) and bounded electrons (inter-band effects). To investigate the metallic part of the plasmonic structure, LD model insert in the Maxwell equations.

To investigate the electromagnetic waves propagation in dispersive media, many various approaches developed [5] such as Finite Element Method (FEM) [6], Perturbation Method (PM) [7] , Beam Propagation Method (BPM) [8] and Finite-Difference Time-Domain Method [9, 10]. Losses of propagation fields in the other approximation methods are bigger than estimated value in FDTD method and can be apply many materials. Therefore, we prefer FDTD method to others [11]. FDTD method can be analyses metallic media at optical and infrared frequencies by solving Maxwell equations for complex geometries [12].

Because of wave propagation maintain in plasmonics at the interface of metal and dielectric boundaries, miniaturization of photonic devices can be made bellow the diffraction limits. From this characteristic properties of plasmonics, there have been many theoretical studies and fabricated works done on dispersive media in literature such as nanoantennas [13, 14], lenses [15, 16], resonators [17, 18], sensors [19] and waveguides [20-22].

In this paper, we design linear nanowaveguides which made of Lorentz-Drude dispersive materials such as Chromium, Titanium, Gold and Silver. We used OptiFDTD software [23] which based on FDTD method for simulation of TE and TM components in nanowaveguides. From obtained graphs, we compared amplitude, strength and dispersion properties of TE and TM through nanowaveguides according to time. We determined more suitable LD materials for nano-photonic devices.

1. **Materials and Methods**

The frequency dependence of the dielectric permittivity can be described as sum of multiple resonances Lorentzian functions in Lorentz dispersion materials,

(1)

here are the resonant frequencies, are the oscillator strength coefficients, are the damping coefficients, is the permittivity at infinite frequency and is the permittivity at .

In the lossless case, Eq. (1) is directly related to Sellmeier equation. In lossy case, the Sellmeier equation can be written in a generalized form shown in Eq. (2).

(2)

Drude dispersive materials are characterized by dielectric function in Eq. (3),

(3)

where, is permittivity for infinite frequency, is the plasma frequency and collision frequency or damping factor.

Some metals complex can be expressed by dielectric function [24]

Intraband effects and interband effects are separated from each other by above dielectric function. The intraband part of the dielectric function is described by Drude model [25]

However, the interband part of the dielectric function is described by semi-quantum model which similar to Lorentz results for dielectrics [4]

where is the plasma frequency, is the number of oscillators, is the m-th oscillator frequency and is the m-th oscillator damping coefficient.

The plasma frequency associated with intraband transistions can be written as,

where is the oscillator strength.

Eq. (4) is more general expression for metals which named as Lorentz-Drude model [26]

(4)

where is the plasma frequency and is the m-th oscillator strength coefficient. If only the term exists and then the general equation describes the Drude model. If terms exist and , then the general model becomes the Lorentz model.

Above we described Lorentz-Drude model in frequency domain. For fullwave analysis of Lorentz-Drude materials we need to transpose from the frequency domain Lorentz-Drude model to time domain. This transformation can be made by using the polarization field within Maxwell’s equations. Lorentz-Drude model in time domain can be expressed as,

(5)

(6)

We can write relations between polarization-electric field and polarization-magnetic field such as,

If we use relation between polarization and electric-magnetic fields then by taking the Fourier transform of the Maxwell’s equations we obtained Eq. (7)

(7)

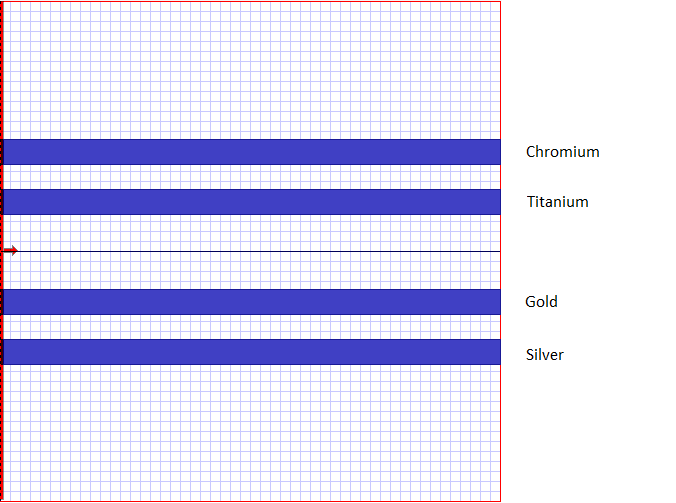
which FDTD algorithm can be derived from it.

1. **Results and Discussion**

In this work we have performed simulations in OptiFDTD tool. We take wafer dimension and wafer material has taken air. The input plane has taken to be Gaussian modulated continuous wave.

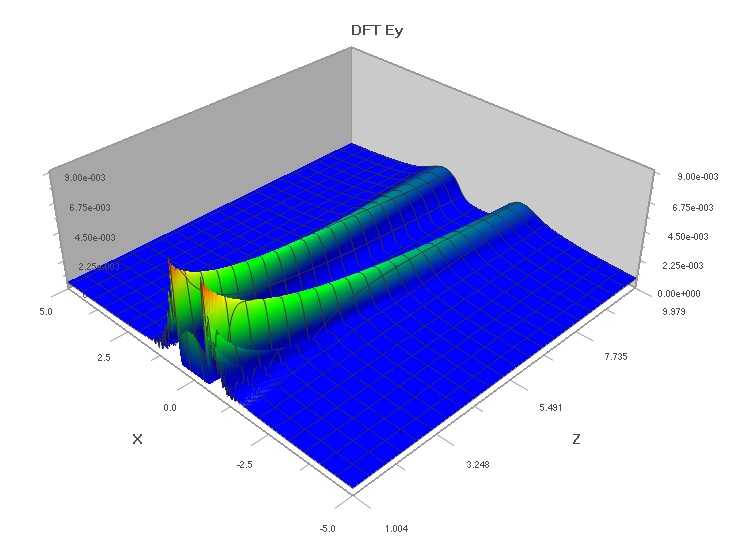
We design linear nanowaveguides which materials are chosen dispersive Chromium, Titanium, Gold, Copper and Silver. The dimension of linear nanowaveguide has taken . Fig. 1 shows the layout of the linear nanowaveguides.

We simulate the electric and magnetic field propagation throughout nanowaveguides. For all nanowaveguides the mesh delta along the x-axis and z-axis has taken . The number of mesh cells along x-axis and z-axis has taken 740 and the simulation selected to be run for 1582 steps.



**Figure 1:** Layout of Nanowaveguides

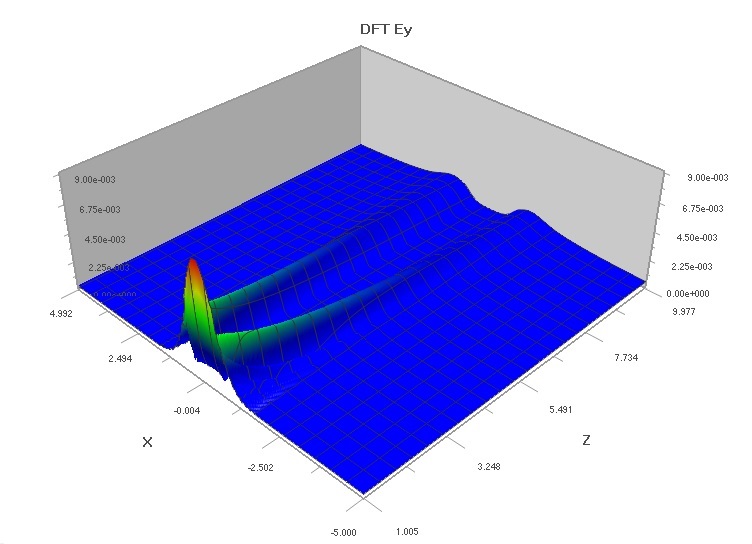
Fig. 2 shows the propagation of electric field components in Lorentz-Drude dispersive materials nanowaveguides.



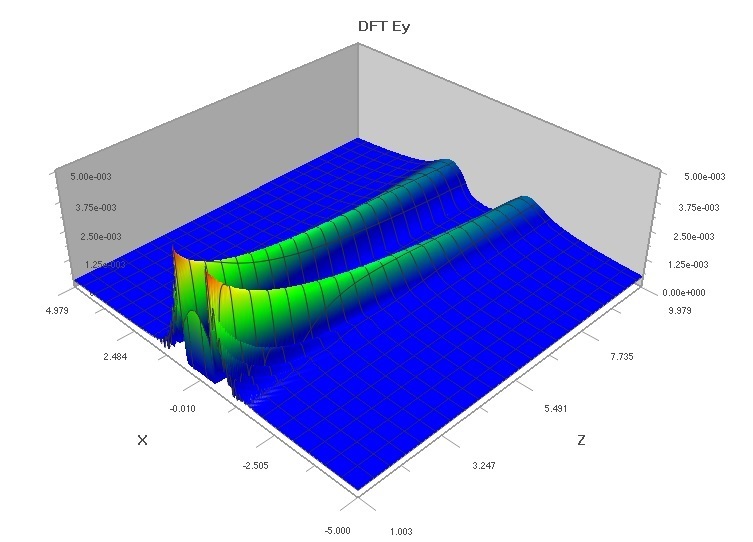
(a)



(b)



(c)

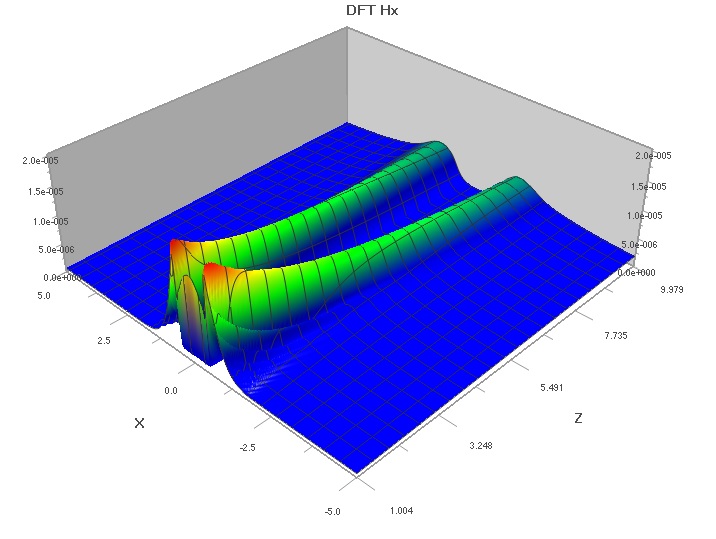


(d)

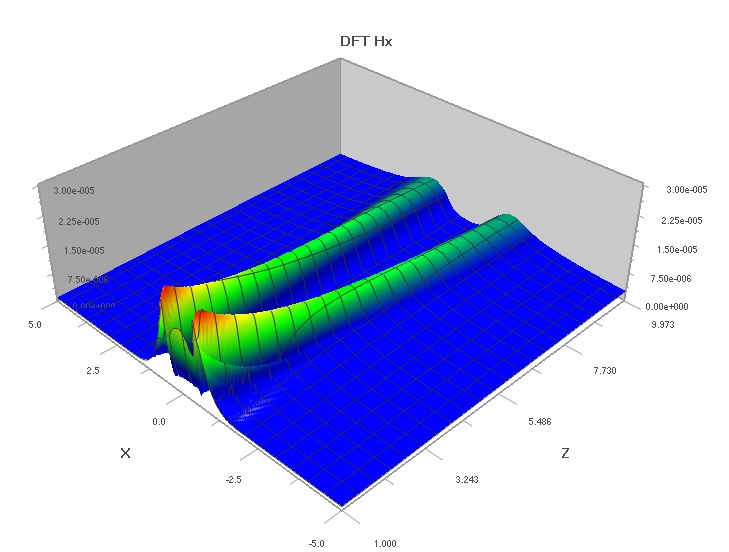
**Figure 2:** The propagation of in (a) Chromium, (b) Titanium, (c) Gold and (d) Silver nanowaveguides.

From Fig. 2 we can see that maximum amplitude of occurred in Titanium nanowaveguide and minimum amplitude of occurred in Silver nanowaveguide. amplitude quickly damped in Gold nanowaveguide as slowly damped in Titanium nanowaveguide.

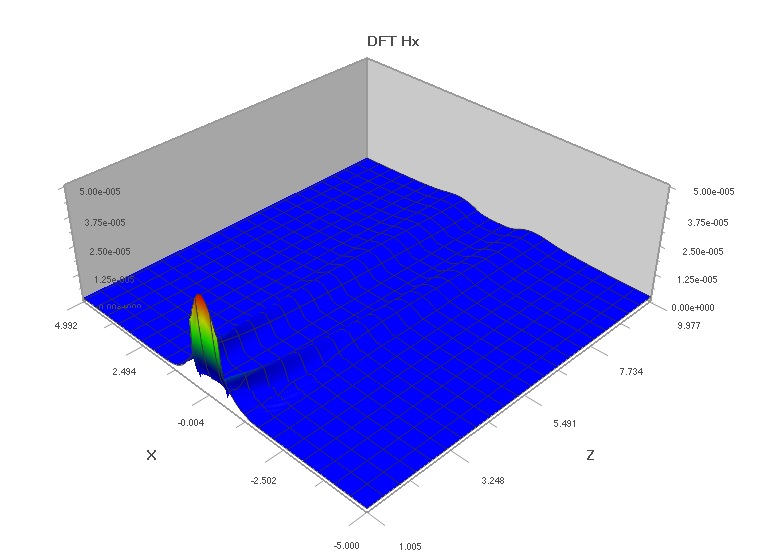
Fig.3 shows the propagation of magnetic field components in Lorentz-Drude dispersive materials nanowaveguides.



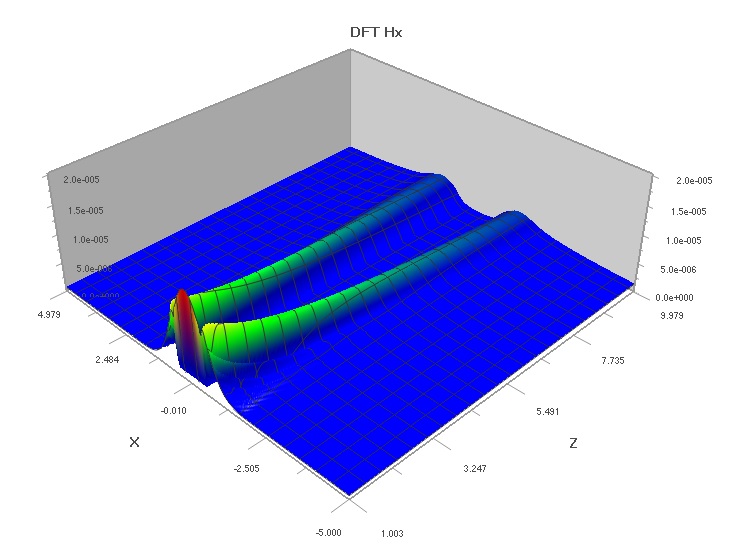
(a)



(b)



(c)

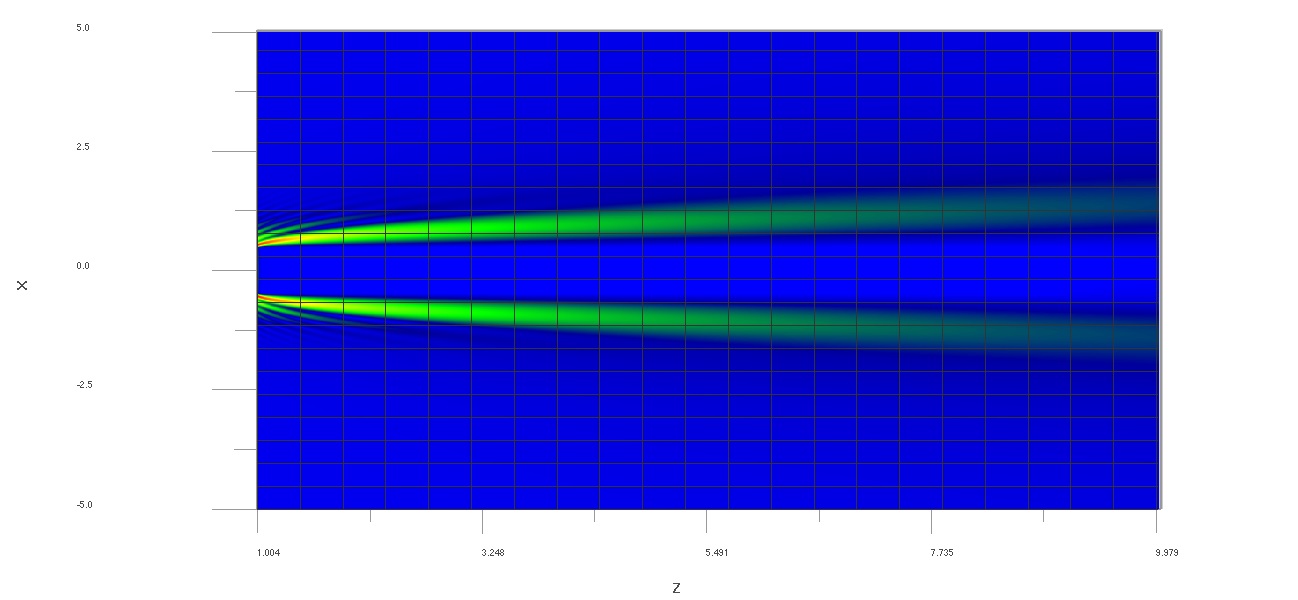


(d)

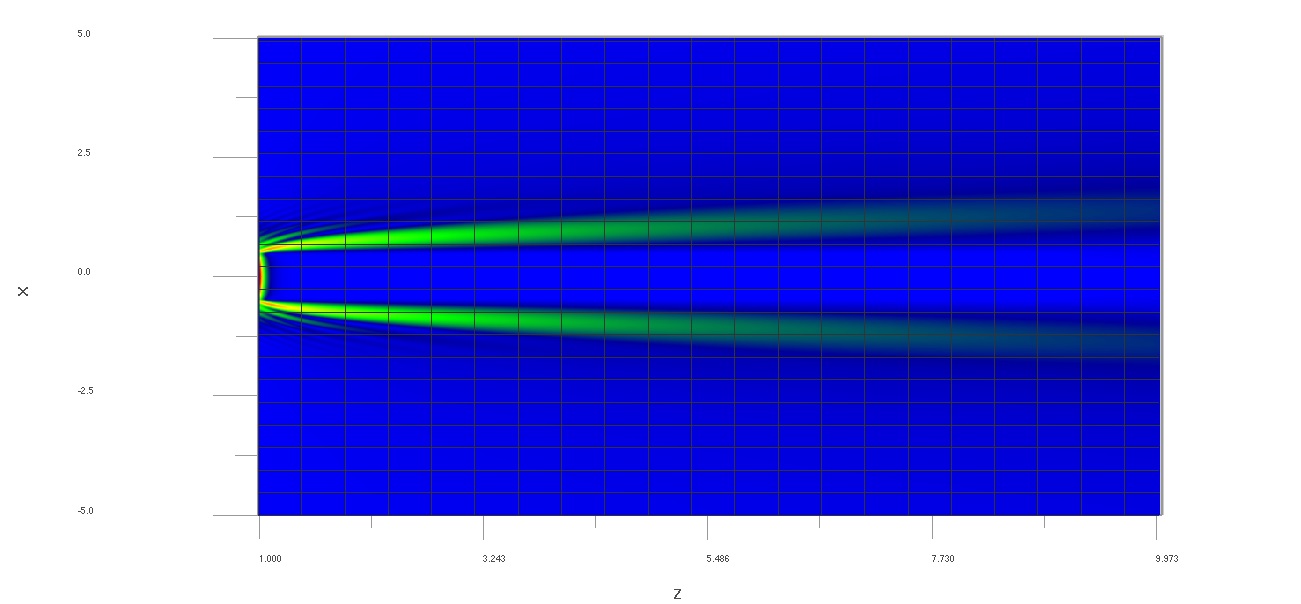
**Figure 3:** The propagation of in (a) Chromium, (b) Titanium, (c) Gold and (d) Silver nanowaveguides.

From Fig. 3 we can see that maximum amplitude of occurred in Gold nanowaveguide and minimum amplitude of occurred in Silver nanowaveguide. amplitude quickly damped in Gold nanowaveguide as slowly damped in Chromium nanowaveguide.

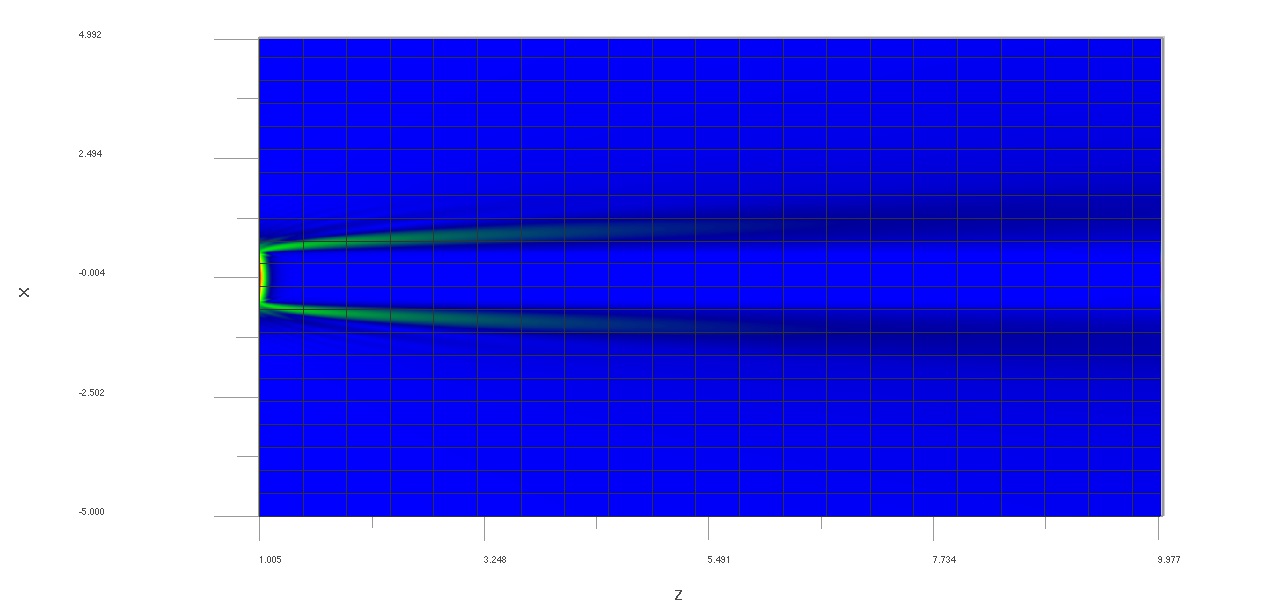
Electric fields dispersions can be seen clearly in Fig. 4 for Chromium, Titanium, Gold and Silver nanowaveguides.



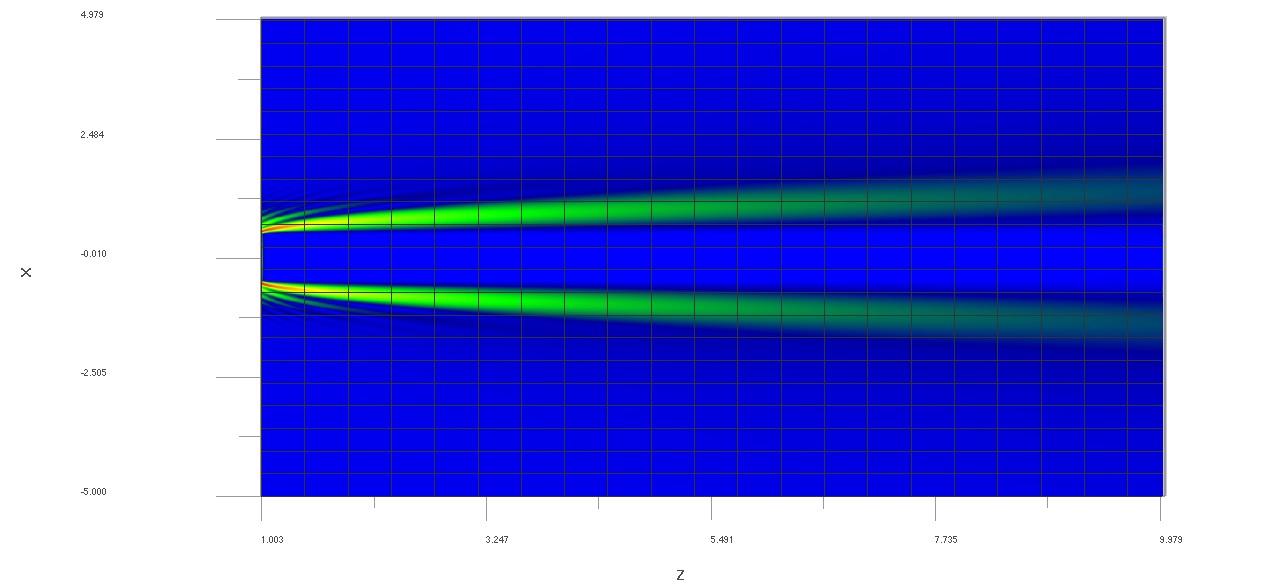
(a)



(b)



(c)



(d)

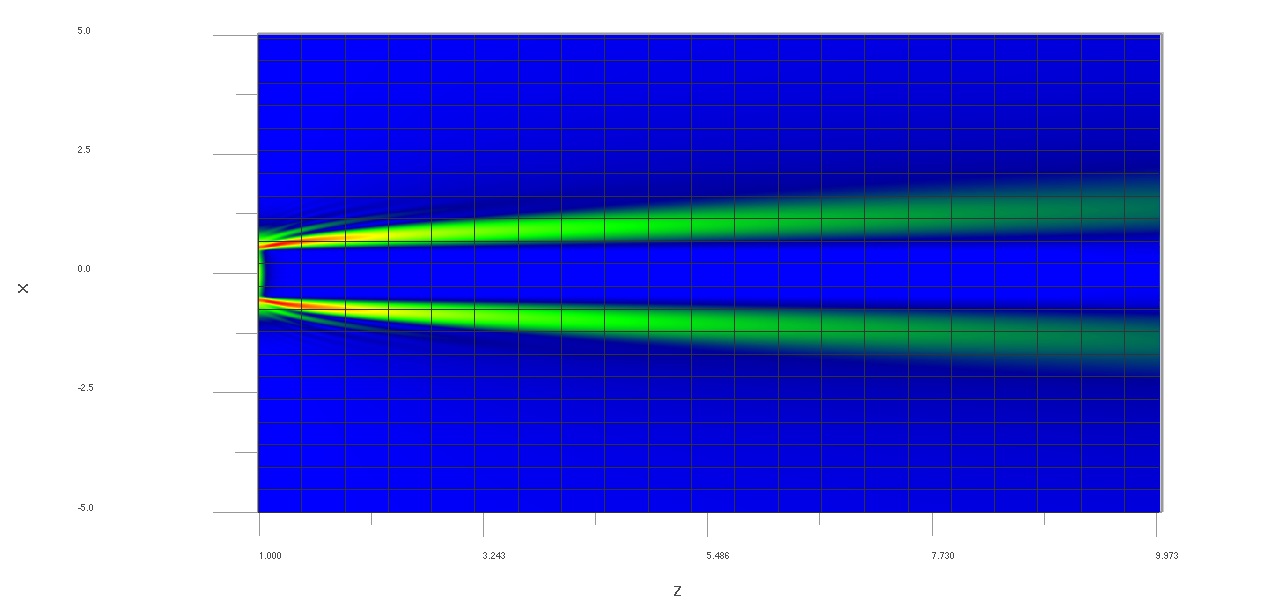
**Figure 4:** The dispersion of in (a) Chromium, (b) Titanium, (c) Gold and (d) Silver nanowaveguides.

Maximum dispersion of has seen in Silver nanowaveguide and minimum dispersion of has seen in Gold nanowaveguide.

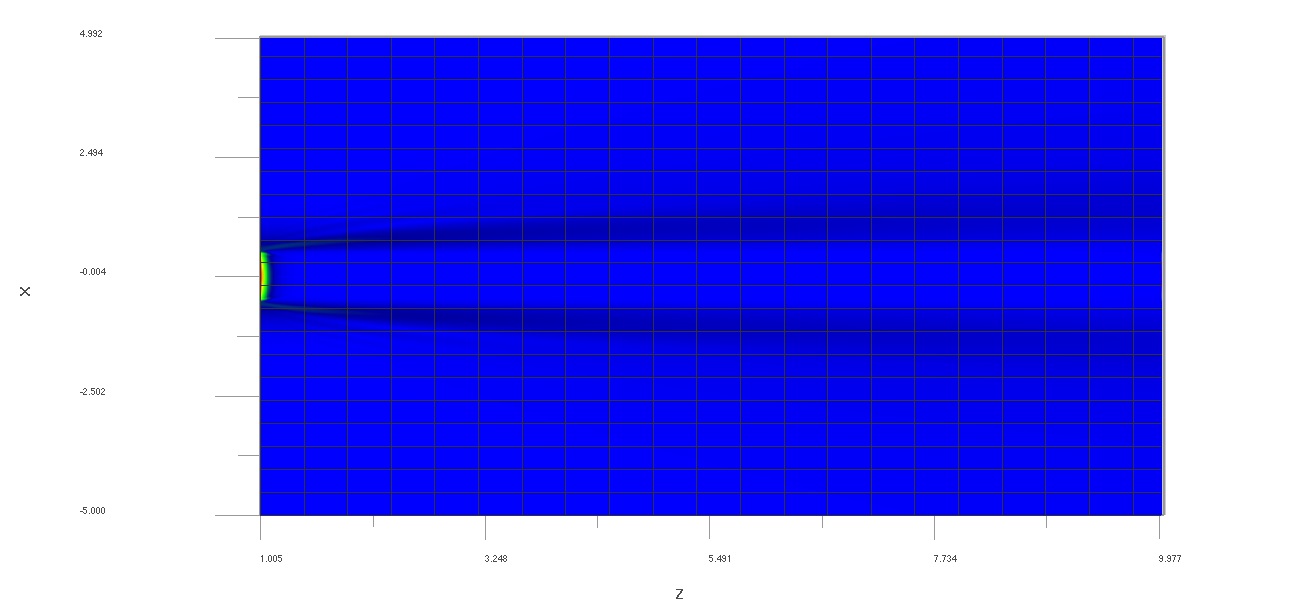
Also, magnetic fields dispersions can be seen clearly in Fig. 5 for Chromium, Titanium, Gold and Silver nanowaveguides.



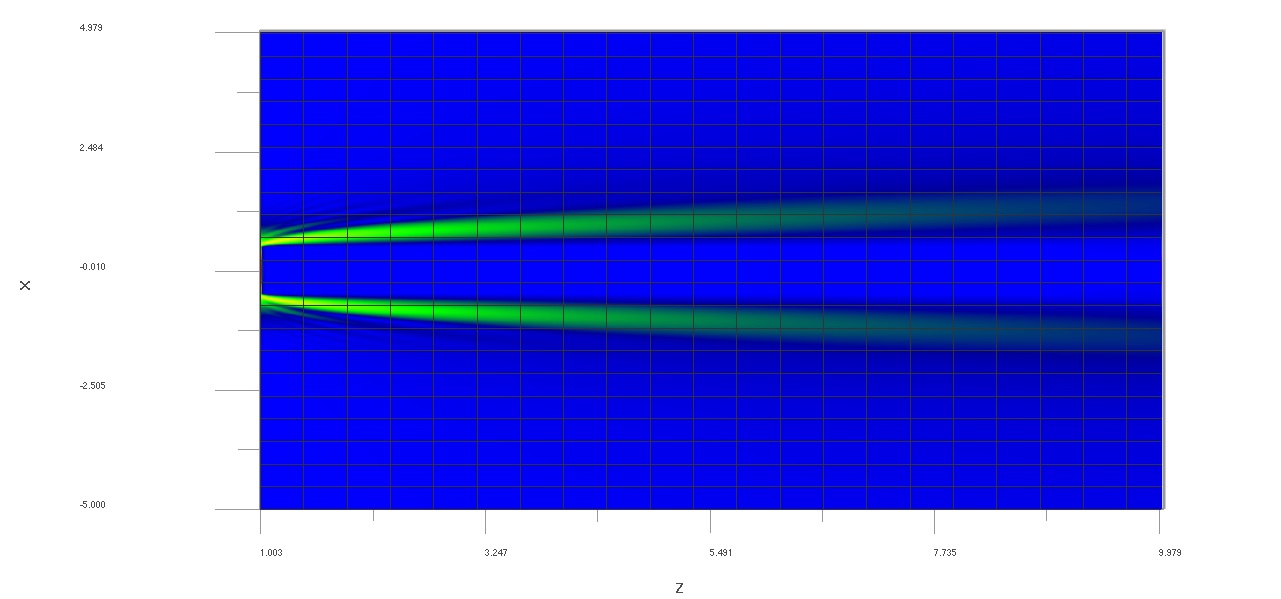
(a)



(b)



(c)



(d)

**Figure 5:** The dispersion of in (a) Chromium, (b) Titanium, (c) Gold and (d) Silver nanowaveguides.

Maximum dispersion of has seen in Silver nanowaveguide and minimum dispersion of has seen in Chromium nanowaveguide.

1. **Conclusion**

We have theoretically studied maximum amplitude, damp and dispersion of and in Chromium, Titanium, Gold and Silver nanowaveguides. From our simulation results we compared these properties of Lorentz-Drude dispersive materials. We have determined maximum electric and magnetic field amplitudes at different materials. Also, we obtained damping and dispersions in different materials. Our results demonstrate that the maximum amplitude of is observed in Titanium nanowaveguide and minimum amplitude of is observed in Silver nanowaveguide. amplitude quickly damped in Gold nanowaveguide as slowly damped in Titanium nanowaveguide. The maximum amplitude of is observed in Gold nanowaveguide and minimum amplitude of is observed in Silver nanowaveguide. amplitude quickly damped in Gold nanowaveguide as slowly damped in Chromium nanowaveguide. The maximum dispersion of has seen in Silver nanowaveguide and minimum dispersion of has seen in Gold nanowaveguide. The maximum dispersion of has seen in Silver nanowaveguide and minimum dispersion of has seen in Chromium nanowaveguide. As a consequence, these results paved the way for us to choose more suitable materials for our purpose in nano optical devices.

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