Low-Dispersive Dielectric Mirrors for Future Wireless Terahertz Communication Systems

Ibraheem A. Ibraheem, Norman Krumbholz, Daniel Mittleman, and Martin Koch

***Abstract*—Dielectric reflectors have recently been proposed to be a key component for future wireless terahertz communication systems. Here, we investigate the dispersion properties of a mirror which consists of nine layers of two different dielectric materials. The layers differ considerably in their refractive index. The structure is highly reflecting and omnidirectional in a very broad frequency band. We find that the group delay is in the order of picoseconds inside the frequency band of interest (330–370 GHz), which is an acceptable value for such a component.**

***Index Terms*—Dielectric mirrors, sub-millimeter wave communication, terahertz (THz) communication, wireless local area network (LAN).**

I. INTRODUCTION

HIGH-SPEED wireless local area networks have evoked considerable interest during the last years. It is expected that a wireless data rate of several Gb/s will be required within the next 10 to 15 years [1]–[3] to satisfy the increasing bandwidth demand. High definition television (HDTV) is only one application that needs 10 Gb/s or more [4] to be transferred uncompressed. In order to achieve the required bandwidth, future short-range indoor communication systems will possibly work at several hundred gigahertz, i.e., in the terahertz (THz) range. In this frequency range high atmospheric and free space losses have to be compensated. Although there is a frequency window of about 40 GHz around 0.35 THz with low attenuation of less than 40 dB/km such a system will require highly directive antennas which lead to a directed transmission between a transmitter and a receiver. To avoid shadowing, e.g., by randomly moving people, such systems should make use of non line-of-sight paths that involve one or more reflections off the walls. The reflectivity of standard building materials in an indoor environment at THz frequencies is very low [5]. A dielectric mirror can increase the reflected power considerably. Propagation analysis shows that only some “hot spots” need to be covered with such mirrors [6] to enhance the performance of the system significantly.

In order to build efficient components for high-speed communication systems intersymbol interference (ISI) has to be considered. The Nyquist ISI criterion defines how to equalize an ISI distorted channel in a bandlimited environment. The more the channel is distorted, the more complex the equalizer becomes. However, equalization is limited. Hence, it is important to minimize the dispersion of each component of a communication system.

Here, we investigate the group delay of an omnidirectional terahertz mirror for various angles of incidence, both for s- and p-polarization. This reflector follows the approach of dielectric mirrors that are well established in optics. The first terahertz mirror was demonstrated in 2002 by Turchinovich *et al.* [7]. Compared to optical wavelengths, sub-mm waves are rather long. Hence, the quarter-wave thick layers of the dielectric structure have to be in the range of approximately 30 to 500 μm depending on the refractive index of the material and the central frequency of the stop band for which the mirror is designed. As most polymers are transparent for sub-mm waves, standard plastic foils can be used to build a terahertz mirror. In order to achieve a flexible and cheap plastic foil with a higher refractive index, additives such as silicon powder can be mixed into to the polymer matrix [8]. Stacking two foils with a high step in the refractive index results in a flexible mirror with a very broad and omnidirectional stop band. Here, we study the dispersive properties of a reflector which was recently demonstrated [6]. Since it contains crystalline pure silicon layers it is not flexible. Nevertheless, it can serve as a representative structure to study the group delay of omnidirectional dielectric terahertz mirrors.

II. MIRROR STRUCTURE AND EXPERMENTAL SETUP

The dielectric mirror consists of a stack of alternating layers of polypropylene and high-resistivity silicon. Four layers of silicon with a refractive index of 3.418 and a thickness of 63 μm are sandwiched between five layers of polypropylene with a refractive index of 1.53 and a thickness of 150 μm. The polypropylene foils are used as outer layers to protect the fragile thin slices of silicon. The sample is clamped in a metal holder, which generates little bending of the mirror. Hence, air pockets trapped inside the stack slightly modify the response characteristic of the reflector [9].

For the characterization of the structure we use a THz time-domain spectrometer [9]. THz pulses generated by a photoconductive switch are guided by high-density-polyethylene (HDPE) lenses and focused onto the mirror. A photoconductive dipole antenna based on LT-GaAs detects the reflected signal. The sample pulse is compared to a reference signal. In order to measure an almost perfectly reflected and synchronized reference pulse we replace the THz mirror by a polished copper plate. After a fast-Fourier-transformation (FFT) of the measured pulses the spectrum of the sample pulse is divided by the spectrum of the reference pulse. Thus, we obtain the frequency dependent reflectivity of the mirror and its dispersive

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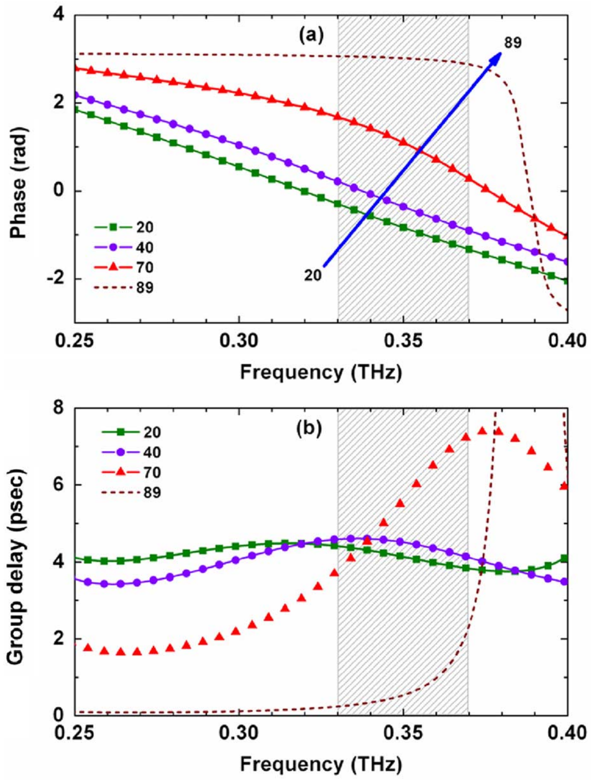

Fig. 1. Simulated reflected phase (a) and the associated group delay (b) for s-polarization and for different incidence angles.

properties. We calculate the group delay from the obtained phase information.

III. SIMULATED AND MEASURED RESULTS

To simulate the phase of the reflected signal as a function of frequency we use the transfer matrix method [10]. Fig. 1(a) shows the simulated unwrapped phase for various incidence angles and s-polarization. The phase decreases almost linear in the frequency range between 0.25 THz and 0.4 THz for angles of incidence below 40°. This behaviour is expected as the phase within the reflected band follows a linear evolution as a function of frequency [11]. For higher incidence angles a micro cavity inside the dielectric mirror is formed because the quarter-wave condition is no longer fulfilled. Hence, an increasing convex shape of the graphs can be observed. At an incidence angle of 89° a considerable phase jump occurs at around 0.4 THz where a prominent narrow band of high transmission is located [6] which is caused by the micro cavity. Fig. 1(b) shows the associated group delay. The group delay is in the order of picoseconds, which is a suitable value for such a component. Inside the frequency band of interest (330–370 GHz), which is indicated by the shaded area, the maximum group delay variation is 4 ps at an angle of incidence of 70° and s-polarization.

Fig. 2 shows the measured phase and the associated group delay for s-polarization and incidence angles from 20° to 70°. Due to setup restrictions [6], [9] no experimental data for very small and very high angles could be acquired. The measured phase response is shown as symbols in Fig. 2(a). This data is in a reasonable agreement with the simulation shown in Fig. 1(a). In order to obtain the group delay the data in Fig. 2(a) have to be differentiated. The small experimental noise on the curves of Fig. 2(a) will lead to severely noisy curves after the differentiation. Hence, we first obtain smooth fits of the phase data [shown as solid lines in Fig. 2(a)] from which we then take the first derivative. The result is the group delay which is plotted in Fig. 2(b). The frequency dependent shape of the curves again agrees reasonably well with the simulations in Fig. 1(b).

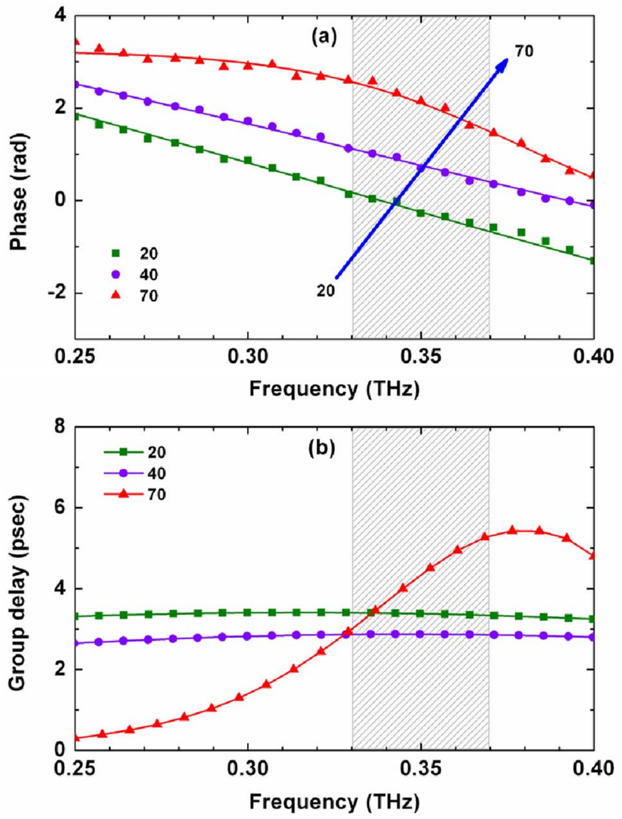

Fig. 2. Measured reflected phase (a) and the associated group delay (b) for s-polarization and for different incidence angles.

Fig. 3 depicts the simulated phase and the associated group delay for p-polarization. Again, the phase response [Fig. 3(a)] has a linear relation over frequency for all incidence angles inside the stop band. The maximum group delay is found at an incidence angle of 20° and is approximately 4 ps inside the bandwidth of interest. Considerable phase jumps occur at the frequencies of very high transmission. Fig. 4 shows experimental results which are in good agreement with the simulation. For the 60° and 70° curves the fits starts after the phase jump.

Obviously the frequency dependencies of phase, group delay and reflectivity (see [6] for the latter) are different for s- and p-polarization. This is expected as the Fresnel equations [12] which describe the behavior of electromagnetic waves (reflection and refraction) when moving between media of differing refractive indices are different for the two polarizations. In particular for p-polarized waves the reflectivity will vanish for a certain angle, the so-called Brewster angle [12]. Since here we have three different kinds of interfaces (between air and the two mirror materials) we also have more than one Brewster angle and the polarization and angle dependent reflectivity spectra of

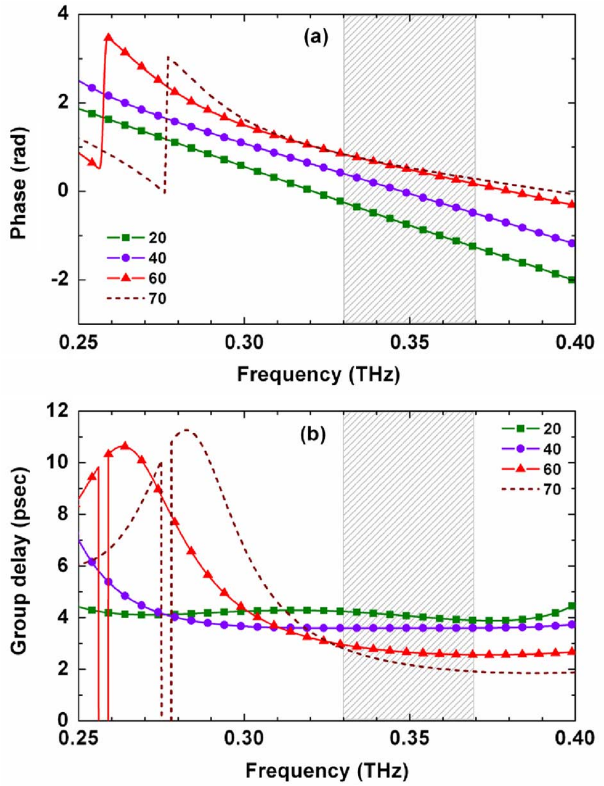

Fig. 3. Simulated reflected phase (a) and the associated group delay (b) for p-polarization and for different incidence angles.

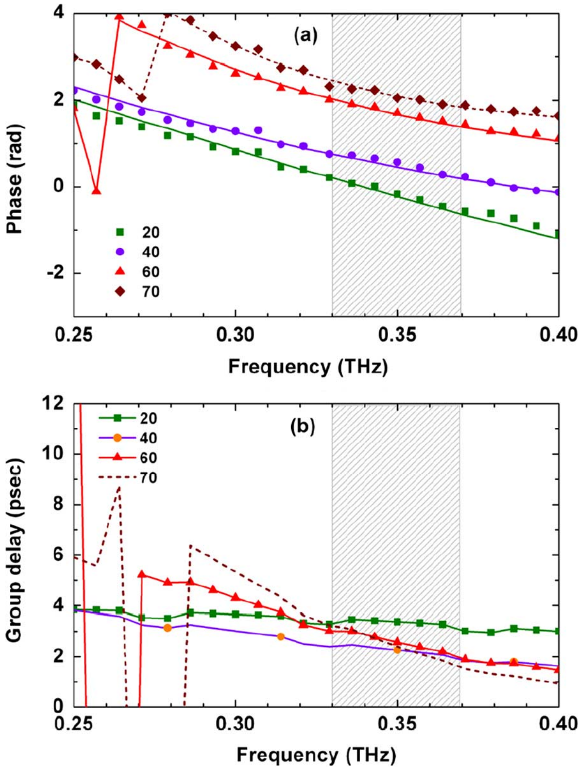

Fig. 4. Measured reflected phase (a) and the associated group delay (b) for p-polarization and for different incidence angles.

the structure and can be only obtained with a transfer matrix simulation [6].

IV. CONCLUSION

We have investigated the dispersive properties of an omnidirectional THz mirror. Experimental data agree well with transfer matrix calculations. The group delay is in the order of a few picoseconds. Hence, we can conclude that dielectric mirrors are well suited as reflectors in future short-range terahertz communication systems.

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