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Mass sensitivity analysis and designing of surface acoustic wave resonators for chemical sensors

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Abstract
The sensitivity of surface acoustic wave (SAW) chemical sensors depends on several factors such as the frequency and phase point of SAW device operation, sensitivity of the SAW velocity to surface mass loading, sensitivity of the SAW oscillator resonance to the loop phase shift, film thickness and oscillator electronics. This paper analyzes the influence of the phase point of operation in SAW oscillator sensors based on two-port resonator devices. It is found that the mass sensitivity will be enhanced if the SAW device has a nonlinear dependence on the frequency (delay $\sim$ frequency^{-1}). This requires the device to generate and operate in a $\omega\tau_g(\omega) = \text{const}$ region in the device passband, where ω denotes the angular frequency of oscillation and $\tau_g(\omega)$ denotes the phase slope of the SAW resonator device. A SAW coupled resonator filter (CRF) that take advantage of mode coupling is considered in realizing such a device to help in shaping the phase transfer characteristics of a high mass sensitivity sensor. The device design and simulation results are presented within the coupling-of-modes formalism.

Keywords: SAW oscillator sensor, sensitivity analysis, SAW CRFs, coupling-of-modes theory, SAW resonator

(Some figures in this article are in colour only in the electronic version)

1. Introduction

A surface acoustic wave (SAW) device, coated with a thin film of analyte-selective material in the region of wave propagation, is used as a frequency control element in the feedback loop of an oscillator circuit in order to make a chemical sensor. Under exposure to target analytes, a variation in the SAW velocity is produced due to surface perturbation. These changes in velocity result in delay variation, which in turn generates a shift in the loop phase, hence the oscillator frequency. The measurement of this shift in frequency defines the sensor response. Thus, chemical sorption on the SAW device surface generates a phase shift in the loop which depends upon the phase transfer characteristics of the device. The resonant oscillations are set up at frequencies for which the single transit loop phase shift is an integer multiple of 2π and the amplifier gain is at least equal to the insertion loss in the feedback path. The signal phase shift around the loop comprises contributions from signal transmission through the SAW device, say $\phi_{SAW}(f)$, where f represents the frequency of oscillation, and the rest of the electronics (amplifier, phase shifter, bonding wire and package parasitics), say $\phi_e(f)$. Therefore, the phase condition of oscillation can be written as $\phi(f) = \phi_{SAW}(f) + \phi_e(f) = -2n\pi$, where n represents an integer. In order for the oscillator to be SAW controlled, the transfer characteristics of the SAW device are chosen to have a narrow passband centered on a desired frequency of oscillation and to have high out-of-band rejection to suppress oscillations at other frequencies. Its delay or phase transfer characteristics are designed to support a single mode of oscillation in the device passband at a minimum insertion loss point. In practice, however, the oscillation frequency may deviate from the minimum loss point if the loop phase shift and amplifier gain conditions are simultaneously satisfied at that frequency [1].

