Micro-scale indentation on active microelectronic circuits to determine the piezoresistive coefficients of transistor channels

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Mobility shifts of the charge carriers in strained CMOS transistor channels occur due to changes of the silicon band structure under strain [1]. This effect is correlated with the used technology and the applied stress-strain fields. The piezoresistive coefficients of the channel material describe the sensitivity of the transistor channels to stress. The mentioned strain effect can be used to enhance the performance of transistors by including stressed layers but can also affect their functionality due to operational parasitic stress. Commonly, such effects are studied with four point bending setups enabling uniaxial stress and a direct feedback of the mobility shift vs. stress correlation [1]. A micro-mechanical test approach using non-destructive elastic indentation (Hysitron TI 950) has been established to study these effects with high local resolution [2]. Particularly, such studies can be used to study localized stress related effects in microelectronic products e.g., due to chip-package-interaction. Prepared flip-chip-packages containing strain-sensitive ring oscillator (RO) circuits are used to monitor the circuit behavior during loading with spherical indenter geometries. The electrical responses of the circuits are compared with the mechanical stress-strain fields of the indentation contact using the finite element method (FEM). To determine the full set of directional stress-strain components and their influence on the RO behavior, different tip geometries for the experimental indentation setup have been selected using parametric FE studies. As a result, cylindrical tips have been introduced to selectively load the circuits [3]. The cylinder orientation according to the transistor channel direction is used to control the stress fields. Subsequently, a combination of three indentation experiments with fundamentally different stress-strain fields (spherical and cylindrical contacts in different orientations) is applied to determine the piezoresistive coefficients of the channel materials of the studied CMOS technology. Therefore, a linear independent set of equations connects the micro-indentation results e.g., RO behavior, the FE-obtained stress-strain fields and enables the determination of the unknown piezoresistive-coefficients, which are in good agreement with literature [1].

References:

[1] Thompson, 2006 IEEE IEDM

[2] Schlipf, 2019 IEEE IIRW

[3] Schlipf, 2020 IEEE IRPS